BC

Ministry of
Forests

PROCEEDINGS OF A WORKSHOP ON

MANAGEMENT OF HEMLOCK DWARF MISTLETOE

August 15 - 16, 1983
Burnaby,
British Columbia

edited by J. Muir, B.C. Ministry of Forests

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Chapter 1
Workshop Opening

*N. Alexander**

* N. Alexander is an instructor at the B.C. Institute of Technology.

The session was opened by Norm Alexander. He asked the delegates, listed in Appendix I, to introduce themselves.

Norm Alexander then introduced Tom Sterner, Pacific Forest Research Centre, Bob DeBoo, B.C. Ministry of Forests and Bob Chisholm, B.C. Institute of Technology, who presented welcoming addresses.

Chapter 2
Welcome on Behalf of the Canadian Forestry Service

*T. Sterner**

The purpose of this session is to discuss recent work done on hemlock dwarf mistletoe and to facilitate interaction between forest managers and researchers, primarily from Pacific Forest Research Centre. The session is jointly sponsored by PFRC, the B.C. Ministry of Forests and the B.C. Institute of Technology. We of the Canadian Forestry Service are pleased to participate in such a session.

C.F.S. is mainly involved in research. Our research, to be of the most value, should be useful to people who are managing forests. First we must work on the right problems and secondly, we must produce results that are meaningful and useful to people such as those attending the workshop. The workshop should be an opportunity for researchers and managers to interact and share ideas. The role of the C.F.S. in this particular workshop is to serve as a resource for the discussions and presentations.

The results presented at the workshop are based on analyses of past work done at P.F.R.C. Presently, none of the researchers are working full time on dwarf mistletoe. Furthermore, the scientists here do not have the final answers.

One of the objectives of the session for the C.F.S. is to determine what unanswered questions are believed to be important. In this session participants also will use the hemlock dwarf mistletoe model called DWARF which is intended as a management tool. Reaction and feedback to the workshop are important to the C.F.S. Therefore participants should participate fully and candidly in the discussions and bring forward their opinions. We thank Norm Alexander of B.C.I.T. for hosting and making the arrangements for this session.

* T. Sterner is the Program Manager of the Pacific Forest Research Centre, Canadian Forestry Service.

Chapter 3
Welcome on Behalf of B.C. Ministry of Forests

*R.F. DeBoo***
W. Young †

Pest management must be founded on the strong base of research and development and must also interact with the foresters and others involved with management. Some important data to keep in mind are that there are approximately two billion cubic meters of western hemlock in the province, most of which are in coastal British Columbia. Approximately 11 million cubic meters are harvested annually. Canadian Forestry Service estimated that losses to dwarf mistletoes are approximately one million cubic meters per year.

If we use an export value of 85 dollars per cubic meter, then the approximate value involved with the volume of hemlock, the amount cut and the amount lost to dwarf mistletoe can be determined by multiplying these figures by 85.

The Ministry believes that diseases are insidious and we should make slow and steady progress by good silvicultural prescriptions. Most of the business of pest management is accomplished by silviculture. There is no prospect of undertaking spray operations or similar types of programs to control dwarf mistletoe.

The role of the Ministry is to develop and implement forest pest management guidelines based on research data and efforts of the Pest Management coordinators and the Branch specialists. The Ministry is looking for recommendations from the workshop to develop appropriate guidelines and policy. The basic prerequisite for any pest management is of course detection. The second prerequisite which perhaps is more important, is appraisal, i.e. what does dwarf mistletoe mean in Timber Supply Areas and in management plans for specific operational areas. Finally, what are the important silvicultural practices to apply, both indirectly and directly to control the hemlock dwarf mistletoe? Another objective of this workshop is to foster communication between foresters, researchers and pest managers and to encourage their collaboration.

** R. DeBoo is the Manager of Pest Management, Forest Protection Branch, B.C. Ministry of Forests.

† W. Young is the Chief Forester, B.C. Ministry of Forests.

Chapter 4

Welcome on Behalf of B.C. Institute of Technology

*R. Chisholm**

* R. Chisholm is the Chairman of the Forest Resources Department, B.C. Institute of Technology.

First I would like to welcome you, on behalf of the Institute and also on behalf of the Forest Resources Department. Norm Alexander has played a major role in educating people in pest management. It is gratifying to see that pest management is now receiving more attention. Logging and fire management have had the major limelight in the last few years. However pests are becoming one of the major harvesters of timber.

I am also pleased to see the participation of many private companies at this workshop. Until recently, most if not all the pest management work was done by the Federal and Provincial governments. However, when we actually manage the problem, we must have the involvement of the private companies.

Chapter 5

Workshop Objectives and Organization

*J. Muir**

* J. Muir is a Forest Pathologist at the Forest Protection Branch, B.C. Ministry of Forests.

One of the major questions facing the Ministry of Forests is whether hemlock dwarf mistletoe has a significant impact on the growth of infected hemlock forests. Recommendations for control of hemlock dwarf mistletoe have been based on Canadian Forestry Service impact studies and estimated growth losses. Recently however, several foresters and researchers have questioned whether hemlock dwarf mistletoe has any significant impact in young, second-growth forests. Another question is what management or silvicultural practices are appropriate for mistletoe-infected hemlock stands?

The main purpose of the workshop is to present and discuss impact data from young stands collected by the late J. Baranyay of the C.F.S., which recently were analysed by Drs. Bloomberg, Thomson and Alfaro. A hemlock dwarf mistletoe computer model (DWARF) developed at P.F.R.C. will be demonstrated to show different options for managing dwarf mistletoe-infected western hemlock stands.

The Ministry of Forests incorporated information provided by C.F.S. and opinions from participants at this workshop into guidelines to manage dwarf mistletoe-infected hemlock stands. We required information on what was feasible or practical and also on thresholds or situations where different silvicultural options or treatments are needed.

The first speaker in this workshop, Dick Smith, discussed the biology of dwarf mistletoe on hemlock. This review concentrated on the features involved in the spread of dwarf mistletoe.

Rene Alfaro discussed the surveys and appraisals that were undertaken by Joe Baranyay at seven locations in the coastal stands. The incidence of dwarf mistletoe on a plot and stand basis was examined. Rene also discussed some of the difficulties and complexities involved in surveys of infected stands.

Alan Thomson discussed the analysis of stem growth data that Joe Baranyay collected to determine the impact of dwarf mistletoe on growth of young hemlock trees. This is a very complex subject and we need considerable discussion of the complexities and variables involved. Some quantitative estimates of dwarf mistletoe impact were made, and there were some other good indications of significant effects of dwarf mistletoe in second growth forests.

On the second day, Bill Bloomberg and Rene Alfaro discussed silvicultural control strategies. A major means of doing this was the computer model DWARF which showed the build-up of mistletoe on hemlock in young stands. The model is limited in application and restricted to young stands on the coast.

Finally, we emphasized the informal nature of this workshop and the need for participants to ask questions and freely discuss the items. We scheduled several hours for individual and group discussions. Another means of providing recommendations and opinions was a workshop questionnaire. Presentations and discussions at the workshop have been summarized in these proceedings.

Chapter 6

Hemlock Dwarf Mistletoe Biology and Spread

*R. Smith**

Dwarf mistletoes, known as Arceuthobium species, are members of the family Viscaceae. The name Viscaceae refers to the viscous coating around the seed. Arceuthobium is the only genus of the family in B.C. There are four species in B.C. mainly on western hemlock, lodgepole pine, Douglas-fir and western larch. The species on western hemlock, A. tsugense, has two races, one on western hemlock and the other on shore pine. The one on shore pine, although not commonly recognized, does considerable damage to shore pine in several locations, particulary on hill tops in the vicinity of Victoria and Sooke. Another area with even more spectacular infection is at Horne Lake, near Qualicum, B.C. This discussion will focus on the hemlock race of the dwarf mistletoe.

Dwarf mistletoes are plant parasites which produce seeds and flowers like other higher plants. The male and female structures are produced on separate plants. Each plant arises from a single seed. Male shoots have very showy flowers with yellow pollen sacs.

* R. Smith is a Research Scientist at the Pacific Forest Research Centre.

Each dwarf mistletoe plant consists of aerial shoots which are visible on the outside of the swollen bark tissues and dwarf mistletoe strands in the bark and wood which are hidden. The dwarf mistletoe plant is perennial and aerial shoots can be formed again and again to produce flowers. A female shoot can produce several crops of fruits. Aerial shoots are present year round on the infections. The female plant is the most important for spread as it produces fruits and seeds.

Each dwarf mistletoe berry has a single seed which is forcibly discharged in late autumn in coastal B.C. The seeds are very sticky when they are shot out from the berries. This sticky layer helps them to adhere to hemlock leaves or shoots. The seeds germinate in the following spring.

The first sign of dwarf mistletoe infection is a small swelling at the site where the root (radicle) from the seed penetrated. Swelling usually occurs one to two years following germination, but it may occur within one year. Swellings are usually difficult to see until at least two years from the time when the seeds were dispersed.

Swellings are a response to the presence of the dwarf mistletoe. Photosynthates or foods produced by the tree are concentrated at the site of infection by the action of the dwarf mistletoe. Normally, these nutrients would move from the foliage down into the trunk or root of the tree and would go into production of woody growth inside the bark.

Dwarf mistletoe strands inside the swelling are called the endophytic system. These strands are formed in the inner bark. In the wood, they are embedded as the tree grows in diameter and are known as sinkers. These sinkers do not actively penetrate into the wood but become buried as the branch grows in size. The endophytic system picks up the minerals and photosynthates produced or transported by the tree. They also transfer these nutrients to the aerial shoots.

It takes a large number of dwarf mistletoe infections to cause a significant or detectable impact on the growth of the tree. Small swellings grow in size both outwards on the branch and inwards towards the stem at the rate of one or two centimeters a year.

Another effect of the infection is to cause a proliferation of branches. Apparently dwarf mistletoe has some effect on the hormonal balance of the tree. A mass of branches results which is called a witchesbroom. One or two witches` brooms have no noticeable effect, but on severely infected trees, where growth losses are apparent, there can be several hundred or even thousands of infections.

Even one broom will increase the diameter of the branch that supports it resulting in a larger knot at the stem. This may result in loss in quality of the stem. Also infections on boles or stems of trees result in a decrease in the quality of the wood for lumber. There also tends to be stem breakage at the site of a stem infection.

Another example of damaging infections occurs when infections are established close to the bole on young trees. For some unknown reason, the supporting branch acts like a new leader and turns upwards. This results in a multiple-leadered tree.

The next topic is the life cycle of hemlock dwarf mistletoe. (Fig. 6.1)

Beginning with seed disperal in late September to October when the seeds are forcibly ejected from the fruit, seeds are intercepted by the foliage. With rainfall, the sticky layer becomes quite slippery and the seeds move down a branch either to lodge on the stem at the base of needles or to fall off and either land on lower branches or fall out of the tree to the ground. After some time, the gel around the outside of seed looses its slipperiness and firmly attaches the seed to the branch. The seeds overwinter at this stage until late winter or early spring, when they germinate.

Starting in January or February, a small root or radicle emerges from the seed. Germination continues until March. When the radicle reaches an irregularity in the bark or the base of a needle or other similar obstruction, it forms a structure called a holdfast. Small filaments of the dwarf mistletoe penetrate from the holdfast into the bark and establish an infection.

The first sign of infection, as illustrated previously is a small swelling. However, often small buds are formed prior to obvious swelling.

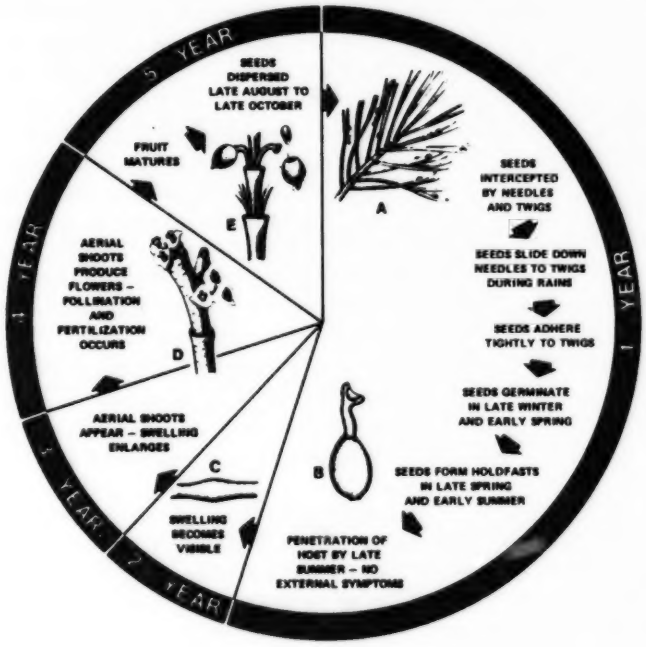

5 YEAR
SEEDS DISPERSED LATE AUGUST TO LATE OCTOBER
FRUIT MATURES
E
A
SEEDS INTERCEPTED BY NEEDLES AND TWIGS
1 YEAR
AERIAL SHOOTS PRODUCE FLOWERS – POLLINATION AND FERTILIZATION OCCURS
D
SEEDS SLIDE DOWN NEEDLES TO TWIGS DURING RAINS
SEEDS ADHERE TIGHTLY TO TWIGS
SEEDS GERMINATE IN LATE WINTER AND EARLY SPRING
AERIAL SHOOTS APPEAR – SWELLING ENLARGES
C
B
SEEDS FORM HOLDFASTS IN LATE SPRING AND EARLY SUMMER
1 YEAR
SWELLING BECOMES VISIBLE
PENETRATION OF HOST BY LATE SUMMER – NO EXTERNAL SYMPTOMS
2 YEAR

Fig. 6.1

Generalized life cycle of dwarf mistletoe:

A. Needle angles as they affect dwarf mistletoe seed movement.

B. A fully developed dwarf mistletoe seedling with holdfast.

C. Small branch swelling is the first indication of dwarf mistletoe infection.

D. Male (staminate) flowers of dwarf mistletoe.

E. Dwarf mistletoe seed discharge.

Swelling usually occurs by the second year after seed dispersal. Aerial shoots are formed either at the end of the second year or the next year. Flowers are formed in the third or more commonly fourth year. Because seeds take one year to develop, the first fruit production and seed production takes place at least four years after seed dispersal.

Now, some parts of the life cycle that are important for spread and build-up of dwarf mistletoe should be examined in more detail.

The first item is seed dispersal. Seed dispersal from an isolated residual tree is shown in Fig. 6.2. Seeds were caught to a distance of up to 16 meters from the residual tree. Although some seeds can be dispersed to 16 meters, most seeds land within two to four meters of the source.

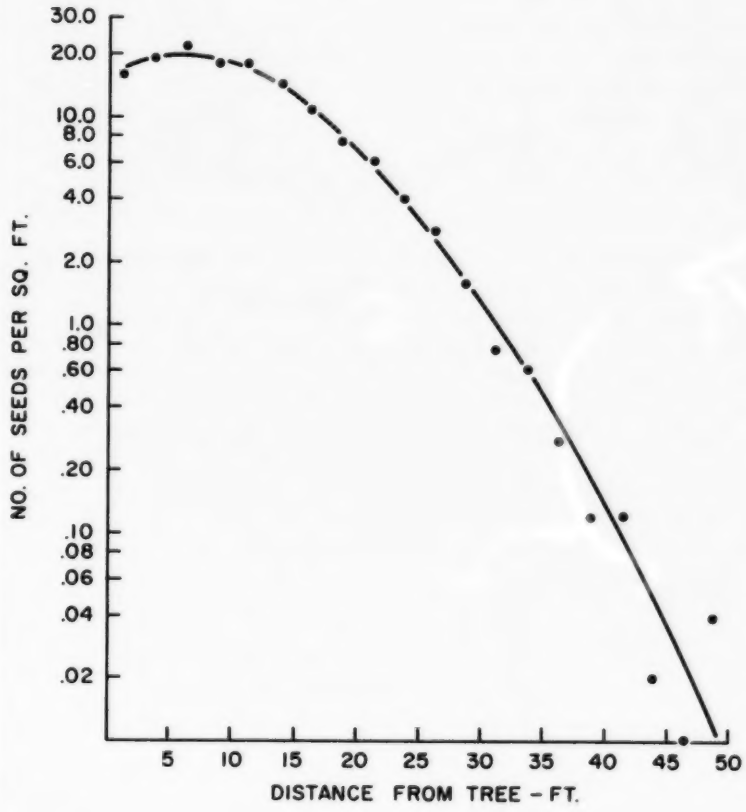


Fig. 6.2

Concentration of dispersed seeds trapped from 0 to 50 (0-15 m) ft from the bole of a source tree

The fate of seeds encountering or coming close to target trees, is another important aspect. First, seeds may pass directly through the crown, this is called throughfall (Fig. 6.3). Also some of the seeds miss the tree completely. Some seeds that are intercepted by foliage are washed off during the winter by rain or snow. This is termed indirect throughfall. Other seeds are retained through the winter and may cause infection.

Data on infection have been collected for several years. Of 100 seeds dispersed into the air space of a target tree, approximately 37 were intercepted and retained over the winter. Of these 37 seeds, 23 germinated and 13 were successful in causing new infections. Compared to results of studies in Oregon and Alaska, these data indicate that the infection level is somewhat higher in south-coastal B.C. than in other areas.

The next aspect of spread is seed movement from a source tree to other nearby target trees. First, it takes approximately five years for infections to begin producing seeds. During these five years, the tree is growing outwards and the infection tends to become buried within the crown as illustrated in Fig. 6.3. Seeds are produced only on one-half of the infections, because male plants do not produce any seeds.

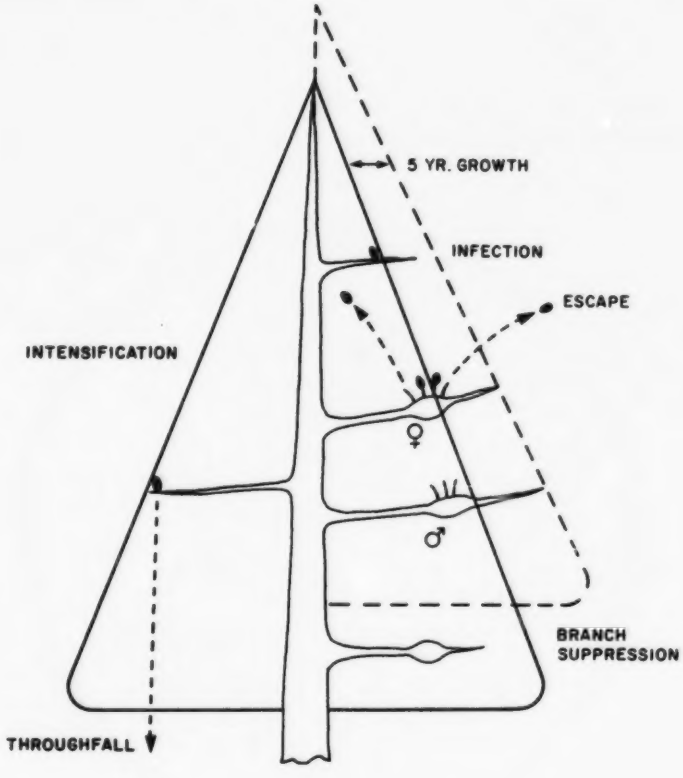


Fig. 6.3

Within-tree factors affecting dwarf mistletoe intensification and spread

Infections located at the outer edge of the crown, disperse about 70% of the seeds towards the outside of the tree and about 30% inwards. These data came from seed trapping experiments and also from observations on the directions in which dwarf mistletoe berries are oriented. Of the seeds shot towards the outside of the tree, only approximately 40% were successful in escaping from the crown. Infections located further in towards the bole or stem, may have only 20% to 30% of seeds escape.

Infections close to the bole have berries orientated in a non-directed manner, that is they do not point consistently towards the outside of the tree, like the ones located at the edge of the crown. However, berries are oriented so that 80 - 90% of the seeds are shot in an upwards direction, rather than downwards.

The next aspect of spread is the fate of the seeds shot from a tree. A tree situated within two to three meters of a source tree will tend to block or intercept 95% of the dispersed seeds. Very few seeds go over a blocking tree and land on another tree behind it.

If the blocking tree is a hemlock, there will be in time a reciprocal dispersal between the two trees, which will result in more infections being formed on the source tree, than if it were standing by itself. If the blocking tree is a non-host species, it will not only prevent the spread to an adjacent tree, but also reduce the build-up of infections on the source tree.

Figure 6.3 also illustrates that as the tree grows upwards and outwards and infections become buried in the crown, infections lose vigour and produce fewer shoots and berries. This is apparently because of shading. Also infections are lost because of the death of small branches. On most infections, maximum seed production occurs from five to ten years and then falls off very rapidly with increasing age.

Figure 6.4 shows the relationship between the numbers of infections initially formed and mortality with increasing age of infection. Mortality varies of course with the density of the stand, vigour of the trees, height growth and other factors. Data from trees 15 years age, show that only 60% of infections survive to age 12 years old. Infections on the main stem of the tree do not suffer the same rates of mortality. They will remain alive until the tree itself dies.

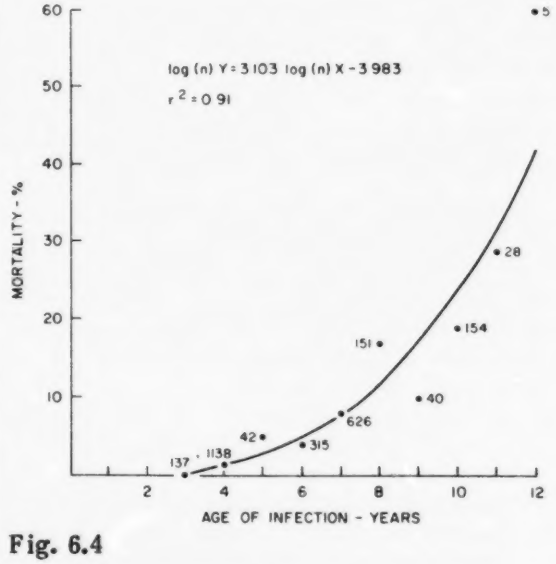


Fig. 6.4

Relationship of age of infection (x) to cumulative rate of mortality (y) for x = 3 to 12. Numerals next to plotted points are numbers of infections on which the mortality rates were based.

Mortality rates of infections also depend on the size or order of branching. Infections on third, fourth or fifth order branches, the small branches, die very quickly, whereas those on the larger main branches, second or third order branches, grow for longer periods, produce more berries, and are more important in terms of impact on the growth of the tree. Many infections on a hemlock have little effect on the growth of the tree, because they are located mostly on the small branches, they die quickly and do not grow to a large size. Bole infections are not very important for seed dispersal, because there are relatively few of them and also because they are shaded and do not produce many berries. Although Fig. 6.4 illustrates a very steep mortality rate, the results cannot be extrapolated beyond the available data, i.e., age 15.

Two other factors affect seed discharge: frosts and hyperparasites. Frost in early September will rupture dwarf mistletoe fruits and prevent seed dispersal. In our studies, frosts damaged up to 80 - 95% of the berries in 2 out of 10 years. Frequency of frost depends on the local topography of the area, and more frequent, severe frosts can be expected in areas with concave relief or profile. Also, much less frost damage can be expected on slopes than on flat areas. There are many hyperparasites known to attack dwarf mistletoe shoots and associated swellings and in some localities, these can drastically reduce the amount of seed production. However, inoculation trials have failed to significantly increase the frequency of infection above that found in nature.

Evidently there are many complicated factors affecting the build-up and therefore the impact of hemlock dwarf mistletoe. These factors were incorporated in a simulation model, DWARF, that will be described later by Bill Bloomberg, which assisted us in determining the influence of certain types and levels of forest management practices on mistletoe spread and intensification.

Chapter 7

Survey and Appraisal of Dwarf Mistletoe in Second-Growth Western Hemlock Stands

*R. Alfaro***

Hemlock Dwarf Mistletoe Distribution in British Columbia

The objective of this presentation is to discuss surveying for hemlock dwarf mistletoe and to summarize survey data collected by the late J.A. Baranyay on seven stands on Vancouver Island and on adjacent islands between Vancouver Island and the Mainland. Before discussing the data I would like to review some general aspects of dwarf mistletoe surveys and how previous surveys for hemlock dwarf mistletoe were conducted.

Hemlock dwarf mistletoe is widely distributed throughout the coastal western hemlock forests, ranging from Alaska to southern B.C., in a band that extends up to 150 km wide into the main river valleys, and in elevation up to 1 500 m. Western hemlock is the dominant species in about four million hectares of forest stands. The Canadian Forestry Service Forest Insect and Disease Survey estimated that 15% of these coastal forests were infected with dwarf mistletoe.

Although several studies have been done for other dwarf mistletoe species, there is relatively little known about the impact of hemlock dwarf mistletoe.

Dwarf Mistletoe Surveys

Two types of surveys can be undertaken for dwarf mistletoe. The first type is a detection, or identification survey aimed simply at establishing the occurrence of dwarf mistletoe in a stand. Determining whether a stand is infected is important so that felling priority can be given to infected trees. Detection surveys can be conducted by crossing a stand along a compass bearing and noting the percent of trees infected. Detection over larger areas has been done by "roadside surveys" where a crew drives along logging roads in susceptible stands, recording the presence of infection. Noting the odometer reading for the start and end points of infected patches it is possible to determine percent infection by calculating the ratio:

$$\text{Percent infection} = \frac{\text{kilometers infected}}{\text{Total kilometers}} \times 100$$

Roadside surveys have been combined to a variable degree with various forms of ground checking including prism or fixed radius plot cruising.

The second type of survey is to determine the severity and distribution of dwarf mistletoe infection in a stand, and the amount of damage sustained to date (current losses). These surveys utilize a systematic layout of plots, either fixed or variable radius, with plot trees rated for infection severity. For current losses, volume loss percentages specific to mistletoe infection severity classes are applied to the volume (or recent growth) of infected trees to estimate growth deficits. Other types of current loss which can be estimated include increased cull associated with mistletoe stem swellings and recent, mistletoe-caused tree mortality.

Several difficulties can be encountered in a survey for hemlock dwarf mistletoe. (To illustrate these points, several slides were presented.) Symptoms to look for in a dwarf mistletoe survey include dwarf mistletoe aerial shoots, witches` brooms, and branch or stem infections. Stem infections are often very difficult to discern because they are concealed by the crown. Often there may be several stem infections on a tree. Many infections in a dormant condition have no aerial shoots and can be very difficult to detect, particularly on the upper crown of trees, on cloudy or dull days and in dense stands. Detection of dormant infections is difficult, particularly by untrained crews. Dormant infections can become active and more apparent following spacing because of improved light conditions and better growth of trees.

As trees grow older, stem infections can develop into large swellings. The impact of these large bole swellings is not well documented. There is apparently not much wood decay associated

** R. Alfaro is a Research Scientist at the Pacific Forest Research Centre.

with these swellings but losses due to increased breakage have been reported as older trees occasionally break at the point of swelling (Fig. 7.1).

Fig. 7.1

Stem swellings caused by the hemlock dwarf mistletoe.

Dwarf mistletoe witches` brooms which result from abnormal multiple branching of infected branches, usually are flat, and palmate and are common on infected trees (Fig. 7.2).

Fig. 7.2

Witches broom caused by hemlock dwarf mistletoe.

Dwarf Mistletoe Distribution in Infected Stands

Distribution of dwarf mistletoe in a stand has important implications for sampling. Mistletoe survival depends on the continuous presence of infected trees from one forest generation to another. Therefore dwarf mistletoe infection, initially, is clumped around infected residual trees left after harvesting or forest fire. This initial pattern is later modified by inter-tree spread of dwarf mistletoe and barriers to spread such as non-host tree species and topographic features. An uneven distribution pattern results when dwarf mistletoe spreads from a marginal source, usually older infected trees into a younger stand (Fig. 7.3a). This is a fairly common situation where a cut boundary has been located adjacent to an infected stand. A management possibility for this situation is to leave resistant tree species such as Douglas-fir adjacent to infected trees or to leave a buffer strip free of trees between infected and planted trees.

(At this point participants discussed factors involved in spread of dwarf mistletoe seed from marginal infected trees to nearby young trees. Paul Wood stated that they were often unable to find any infection of young trees. Rene, Dick Smith and Bill Bloomberg discussed several aspects that might lead to more or less infection in nearby trees. Bill Bloomberg and Rene discussed several of these situations further with the DWARF model.)

Fig. 7.3

Initial pattern of dwarf mistletoe infections (a) marginal infection from a neighbouring infected stand,

A different infection pattern occurs when a stand has been logged and numerous scattered residual trees are left. Depending on the number and distribution of residuals, dwarf mistletoe distribution may be even or uneven (Figs. 7.3b, c). Several slides were shown illustrating the condition of harvested areas, with infected residuals in variable number and distribution, and the types of infection that developed.

Fig. 7.3

(b) uneven or clumped distribution resulting from a few scattered infected residual trees per hectare left after logging, (c) even infection caused by many infected residuals left per hectare.

Stunted infected residuals, i.e., small, weak-looking trees, might not pose much hazard to surrounding new trees in spite of having a high dwarf mistletoe infection rating. Larger residual trees pose a much greater hazard for infecting the next crop. Residuals left on a steep slope lead to a greater spread of infection downslope, but usually less spread upslope. Residuals often are left on ridges or edges of areas that are otherwise cleanly cut.

Rating Systems

A survey of dwarf mistletoe generally involves some rating of dwarf mistletoe infection on individual trees or stands. Infection rating systems are used to rate or code each part of the tree crown or stem. Ratings are summed to obtain a total tree rating. Infected trees are classed as light, moderate or severe, depending on the rating total.

One rating system which is very widely used and accepted is the six point system. In this system the crown is divided into thirds and each third is rated either as zero, one or two according to Table 7.1.

TABLE 7.1
Six point dwarf mistletoe rating system

Rating	Branch infection
0	none infected
1	50% or less infected
2	more than 50% infected

In this system, only the tree crown is rated. A total infection rating of one to two is described as light, three to four as moderate or medium, and five to six as severe. The six point system is used widely in the United States, particularly for lodgepole pine and other species and also used for the hemlock DWARF model. It has been used to correlate infection with growth loss and mortality by lodgepole pine dwarf mistletoe.

One of the shortcomings of the six point system is that it does not include stem swellings or defects. This system is also hard to apply in smaller trees. Generally smaller trees are over-rated. Also in very tall trees, it is very difficult to see the top parts of the crown.

At present the growth impact associated with trees lightly, moderately and severely infected is largely unknown. It is not known whether impact will increase linearly or exponentially with these categories. Also the system does not indicate how hazardous a particular tree is to surrounding trees. A tree may be rated as six, for example, but it may be very weak and dying and present very little hazard to surrounding trees.

Another system, developed by R. Smith and used by Baranyay, is the nine point system. In this system not just the crown, but the whole tree is divided into thirds and each third is rated according to Table 7.2.

TABLE 7.2

Nine-point hemlock dwarf mistletoe rating system.

Rating	Branches	Trunk swellings
0	non-infected	none present
1	few branches infected or no branches on trunk	none one minor swelling
2	nearly all infected or few infected or no branches	 minor swelling(s) more than one minor swelling
3	nearly all infected	more than one major or minor swelling
	no branches	major swellings

NOTE: Minor swelling = a trunk swelling involving less than 25% of the trunk circumference.

Each tree third is rated as: zero, if there are no symptoms of infection; one if it has a few branch infections and no stem swellings or, if the tree has no branches on trunk but has minor stem swellings; two if most branches are infected and no trunk swellings, or if it has a few branch infections and one or more minor swellings on the stem, or if it has no branches but has more than one stem swelling; and three if nearly all branches are infected and there are major stem swellings or if it has many minor and major swellings.

This system has several of the disadvantages of the six point system. For example, it is very difficult to rate the upper crown of the tallest trees. Also, the many categories are difficult to remember by the field crews. However, this system does give a more complete description of the infections on branches and on the stem.

Dwarf Mistletoe Survey Results

Seven stands were sampled at Jordan River, Nitinat Lake, China Creek, Texada Island, Cortes Island, Redonda Island and Holberg Inlet. Forty-five trees were felled at China Creek, Nitinat, Redonda and Jordan River. Ladysmith was another area studied, but it was excluded because it appeared to be a relatively poor site in the Douglas-fir zone and not representative of hemlock forests.

Stand age ranged from 40 to 100 years: 40 to 50 years at Redonda, Texada and Cortes; 63 years at Nitinat; 65 years at China Creek; 70 years at Holberg Inlet; and 100 years at Jordan River.

In each area plots were systematically laid out to determine distribution of dwarf mistletoe infection in the stand, the proportion of hemlock infected and the potential for infection of the next crop. Trees were cut from these areas for stem analysis. Results of the stem analysis were presented by A. Thomson. The percentage of infected trees in the stands ranged from 17% at China Creek to about 90% at Jordan River and Texada Island. Average stand dwarf mistletoe rating, calculated as the mean rating of all plots, increased with the percentage of trees infected from 0.3 to 3.8 (Table 7.3). Distribution of trees/ha or volume/ha by dwarf mistletoe severity class is presented in Tables 7.4 and 7.5.

TABLE 7.3

Mean percentage of hemlock in the stand, percentage of hemlock trees infected with dwarf mistletoe and average dwarf mistletoe stand rating. Standard deviation in brackets.

	Percent hemlock trees	Percent infected hemlock	Stand rating
China Ck.	44 (22)	17 (27)	0.3 (0.7)
Nitinat Lk.	96 (12)	40 (46)	1.3 (1.6)
Redonda I.	84 (24)	44 (48)	1.9 (2.5)
Cortes I.	67 (27)	71 (43)	2.8 (2.2)
Texada I.	72 (25)	91 (25)	3.7 (1.8)
Holberg In.	79 (24)	89 (27)	3.0 (1.7)
Jordan R.	91 (14)	88 (23)	3.8 (1.3)

TABLE 7.4

Number of western hemlock stems per hectare and percentage infected by hemlock dwarf mistletoe, by severity class, in seven coastal stands.

	Total No. stems/ha	Healthy %	Light %	Moderate %	Severe %
China Ck.	408	82.9	9.9	6.6	0.7
Nitinat Lk	353	59.7	26.4	13.9	0.0
Redonda I.	1097	55.6	21.2	17.5	5.7
Cortes I.	747	29.3	27.9	41.4	1.4
Jordan R.	507	11.8	24.4	39.3	24.5
Holberg In.	403	10.6	53.8	35.1	0.5
Texada I.	1178	8.6	36.0	50.0	5.4

TABLE 7.5

Western hemlock volume per hectare (m^3) and percentage of the volume per hectare infected by hemlock dwarf mistletoe, by severity class, in seven coastal stands.

	Total m^3	Healthy %	Light %	Moderate %	Severe %
China Ck.	124	79.6	10.8	9.3	0.3
Nitinat Lk.	751	50.1	21.7	28.2	0.0
Redonda I.	288	45.0	23.1	21.2	10.7
Cortes I.	202	28.1	29.2	41.7	1.0
Texada I.	167	13.8	23.2	53.9	9.1
Holberg In.	636	8.7	55.0	35.6	0.7
Jordan R.	723	5.1	9.6	41.8	43.5

Results from four of the infected stands were discussed in more detail.

In the Nitinat stand, approximately 21% of the volume was made up of trees lightly infected, 28% moderately infected and none severely infected. This stand is an example of marginal infection, where dwarf mistletoe spread from the edge of the stand (Fig. 7.4). More infection was present in the larger diameter trees. In this area, large stem infections (Fig. 7.1) were quite prevalent on approximately 10% of the trees (Table 7.6).

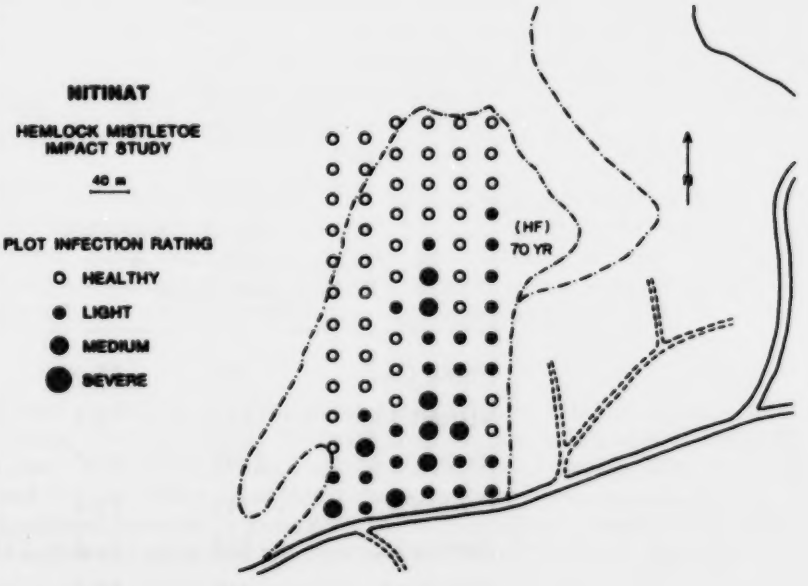


Fig. 7.4

Plots and infection at Nitinat Lake stand.

At Cortes Island, the situation was quite different. There was an even distribution of dwarf mistletoe infection (Fig. 7.5). The stand was 44 years old, was relatively young, and only one plot rated severe. Note that for a plot to rate severe, many trees in the plot must be severely infected with many stem swellings. There were no wolf trees or large residuals infected in this stand. All the crown classes were infected. Fourteen percent of the trees had large stem swellings in the bottom one-third of the tree.

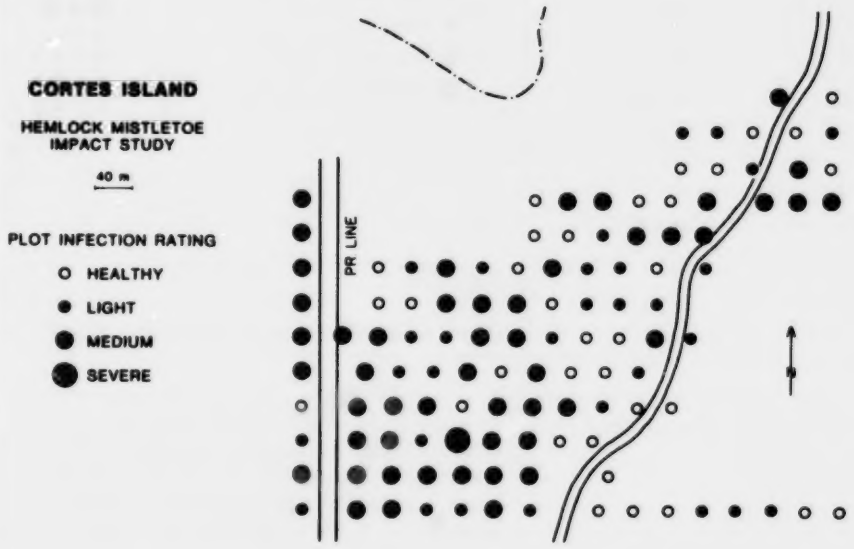


Fig. 7.5

Plots and infection at Cortes Island stand.

On Texada Island a smaller survey of a 50 year-old stand was undertaken. Again there was an even distribution of infections. No plots were rated as severe. There were several large trees that were severely infected which were residuals that survived logging. About 5% of the stems per hectare were rated as severe; this was the most severely infected study area. Fifty percent of the stems per hectare were rated as moderate. About 8% of the trees had major swellings in the lower bole. Taller trees and those in the upper crown classes were severely infected, and also the small trees were infected.

On Redonda Island dwarf mistletoe was quite evenly distributed throughout all crown classes, even in the suppressed crown class. About 23% of the trees were rated as moderately or severely infected. The spatial distribution of the infection was clumped (Fig. 7.6). About 19% of the trees had large stem swellings in the lower bole.

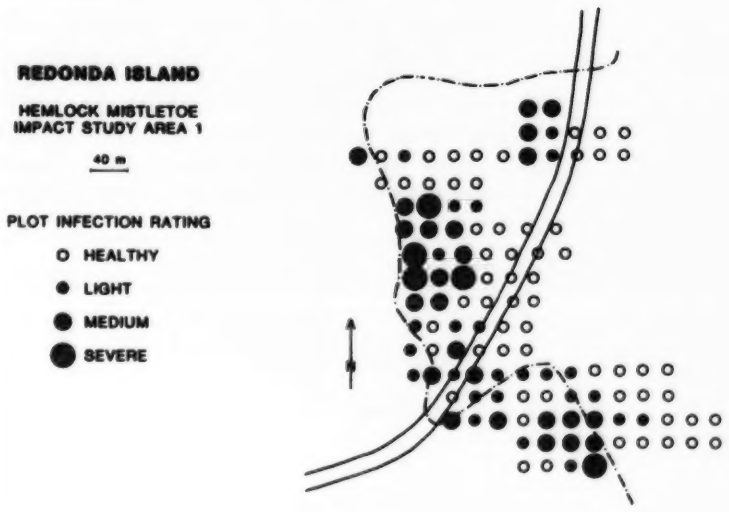


Fig. 7.6

Plots and infection at Redonda Island stand.

Stem swellings were common in the lower bole of trees and an average 9.3% of the trees had major swellings (Table 7.6). In general, tree mortality attributable to dwarf mistletoe infection was low, averaging 0.6% stems per hectare (Table 7.7).

TABLE 7.6

Percentage of trees showing major[1] stem swellings by tree thirds in six British Columbia coastal locations.

	Tree Third		
	Top %	Mid %	Lower %
China Ck.	0.0	0.3	5.2
Nitinat Lk.	0.0	0.0	9.7
Redonda I.	0.0	1.2	19.0
Cortes I.	0.0	2.0	14.3
Texada I.	0.1	1.7	7.8
Holberg Inlet	0.0	0.0	0.0
Average	0.02	0.9	9.3

[1]Major swellings were defined as those affecting 25% or more of the stem circumference.

TABLE 7.7
Mortality in western hemlock attributable to dwarf mistletoe infection in seven British Columbia coastal locations.

Stand	Dead due to mistletoe Stems/ha	%	Dead due to other causes Stems/ha	%
China Ck.	2.7	0.6	5.4	1.3
Nitinat Lk.	0.0	0.0	6.3	1.8
Redonda I.	14.3	1.3	3.6	0.3
Cortes I.	0.0	0.0	146.1	16.3
Texada I.	6.3	0.5	145.7	11.0
Holberg Inlet	0.0	0.0	1.0	0.3
Jordan R.	9.8	1.8	18.6	3.5
Average	4.7	0.6	46.7	4.9

The general conclusion of the surveys was that in all of the 40-100 year-old stands studied, except China Creek, there was a high level of dwarf mistletoe infection.

Chapter 8

Western Hemlock Growth Losses Caused by Dwarf Mistletoe

*A. Thomson**
*R. Smith**
*R. Alfaro**

Introduction

Thomson and Smith (1983) showed that trees at 22 years of age infected by hemlock dwarf mistletoe exhibited slightly reduced height growth, but no reduction in radial growth was detected at breast height. At that early age, mistletoe effects apparently were masked by microsite and competition effects. Mature infected hemlock showed reduced radial growth and annual volume increment (Smith 1969).

Subsequent to Smith's report, data on growth of trees 40 to 110 years from several other locations were analyzed. Smith's original data (1969) were re-analyzed to compare growth patterns (Thomson and Van Sickle 1980). Some information on percentage volume loss was added to this report after the workshop. Much of the information is included in Thomson et al (1984).

Methods

Data were collected by the late J.A. Baranyay from three stands at Redonda Island, China Creek and Jordan River and by Smith (1969) at Cowichan Lake (Figure 8.1). At Redonda Island the stand was 40 year-old hemlock-Douglas-fir which occupied 30.4 ha. The China Creek stand was a 70 year-old, hemlock-Douglas-fir type of 8.2 ha. The Jordan River stand was 110 year-old, hemlock-cedar and extended over 20 ha. The Cowichan Lake stand was 110 year-old pure hemlock, and extended over 0.8 ha.

* A. Thomson, R. Smith and R. Alfaro are Research Scientists at the Pacific Forest Research Centre.

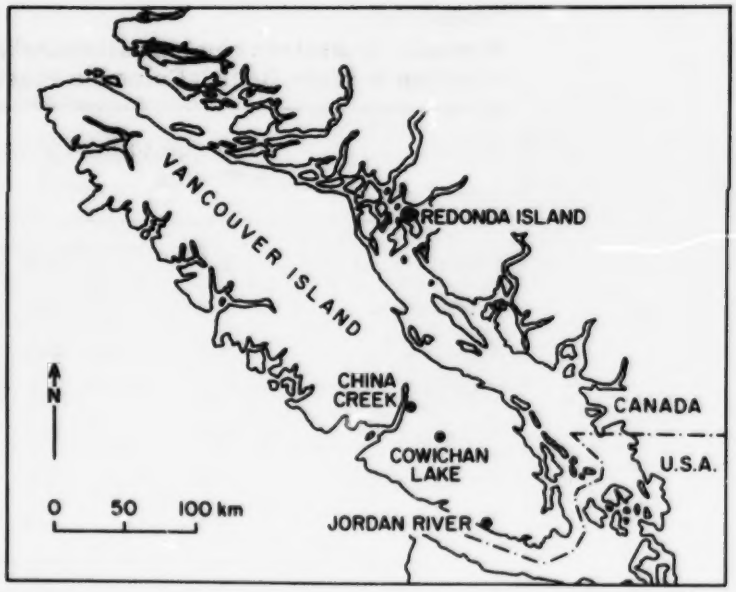


Fig. 8.1

Map of sampled areas

Dominant and co-dominant hemlock trees were rated by the six point (Hawksworth 1961) and nine point (Smith 1969) infection rating systems, and were subsequently grouped in healthy, moderately and severely infected classes. For the purpose of comparison, lightly infected trees of Smith (1969) were assumed to have grown equivalent to healthy trees. In this study, a varying number of trees (usually 15) from each class were randomly selected for study from each stand. Trees were felled and discs removed at 1.0 m intervals (0.5 m interval close to the top of the tree). The length of the live crown was measured. Discs were not taken at a bole swelling. Because of the clustered mistletoe occurrence, different parts of stands were sampled to get healthy trees in the Redonda I., China Cr. and Jordan R. areas. In the Cowichan Lake area, where lightly-infected trees were used as controls, it was possible to take all trees from two adjacent 20 x 181 m strips, where lightly, moderately and severely infected trees were interspersed.

Annual radial growth was measured along two radii on each disc. Diameter, height and volume growth and pattern of radial growth along the bole were determined for all trees using a stem analysis program described by Thomson and Van Sickle (1980).

Results

Healthy Trees as Controls

The average age and volume of the trees in each area are summarized in Table 8.1. Redonda Island and China Creek trees, at 44 and 70 years respectively, provided good coverage of the spread of ages between the 22-year-old trees of the Thomson and Smith (1983) study and the 110-year-old trees of the Cowichan Lake area (Smith 1969). At 106 years, the trees in the Jordan River area were comparable to those in the Cowichan Lake area.

TABLE 8.1

Average age and volume of healthy, moderate and severely mistletoe-infected trees in each area.

Area	Average age (all trees)	Average volume (m^3)		
		Healthy	Moderate	Severe
Redonda I.	44	1.126	0.454	0.409
China Creek	70	1.210	0.758	0.882
Jordan R.	106	3.676	2.278	1.851
Cowichan L.	110	1.877	1.802	2.023

In comparing the volumes, the Redonda I., China Cr. and Jordan R. areas showed greater volume in healthy trees than in the moderate or severe classes whereas the Cowichan Lake area showed less volume in the healthy trees than in the severely infected trees. Both China Cr. and Cowichan L. areas showed slightly lower volumes in the moderate than in the severe class. However, to correctly interpret these figures, the suitability of the healthy trees as controls was examined, as well as the suitability of the moderately infected trees for direct comparison with the severe class. To be adequate controls, the healthy trees should resemble the other classes in age distribution, pattern of early growth prior to any significant mistletoe effects, and silvicultural history.

The average age of trees in each infection class as shown in Table 8.2, was significantly different between each infection class especially in the China Creek and Cowichan Lake areas. Even where the average age appeared uniform, such as at Jordan River, the age distribution was different as indicated by the range and standard deviation of ages.

TABLE 8.2

The average, standard deviation (s.d.), and range of tree ages within each mistletoe infection class from each area.

Area	Healthy			Moderate			Severe		
	age	$\pm$ s.d.	range	age	$\pm$ s.d.	range	age	$\pm$ s.d.	range
Redonda I.	40	2	38-44	46	5	41-56	47	5	41-57
China Cr.	64	4	53-70	65	6	52-73	80	11	63-97
Jordan R.	103	14	96-131	109	18	85-146	105	18	80-143
Cowichan L.	92	19	57-127	113	33	86-201	124	22	93-155

Although healthy and infected trees at Jordan River had a similar mean age, healthy trees were much more even-aged than the mistletoe-infected trees with 74% of the healthy trees of age 98 ± 1 years. Similarly, healthy trees at Redonda Island were more even-aged, with 80% of healthy trees aged 39 ± 1 years. This was reflected in the low standard deviation of ages at Redonda, but at Jordan River, the standard deviation was relatively high due to the presence of older residual trees.

Height growth curves or dbh growth curves were compared to evaluate comparability of early growth patterns and stand history in the different infection classes. Figure 8.2 illustrates this procedure for height growth of the China Creek trees. Both the moderately and severely infected trees showed a pattern of early suppression followed by release in the early 1930's. The healthy trees show a more regular increase in height. The patterns of growth were sufficiently similar that an average of the tree growth patterns accurately represented the growth of all the sample trees in an infection class.

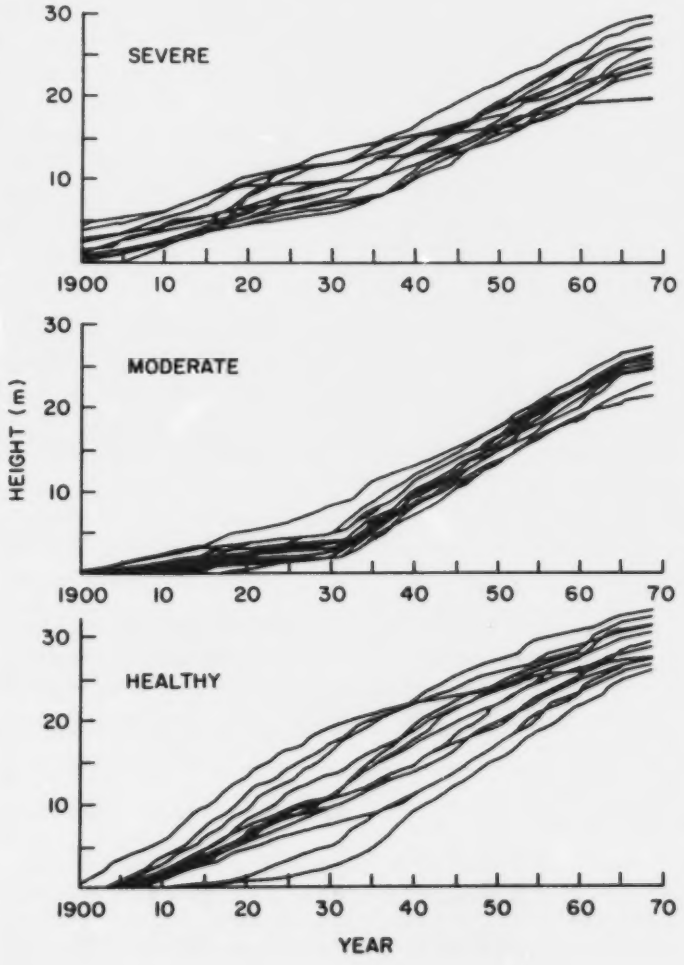
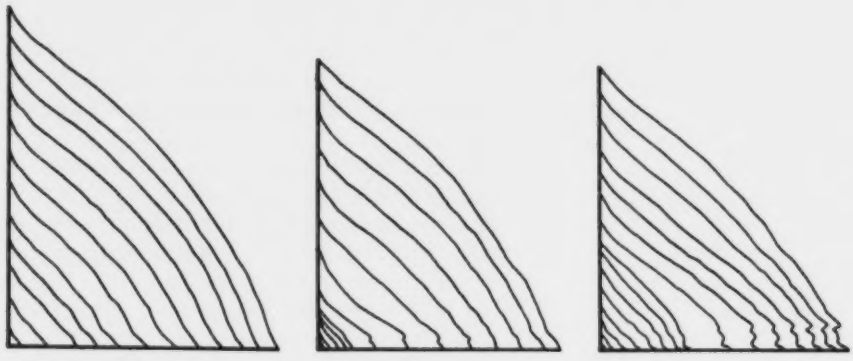


Fig. 8.2

Height growth patterns of China Creek sample trees.

The system described by Thomson and Van Sickle (1980) was modified to calculate an average growth profile. Comparisons of these average tree profiles for the China Creek trees (Figure 8.3) emphasized the pattern of early suppression followed by release of the moderately and severely infected trees and the regular growth of the healthy trees.



(a) healthy (b) moderate (c) severe

Fig. 8.3

Average growth profile of (a) healthy, (b) moderate, and (c) severely infested trees from China Creek. For explanation of basal irregularities see text.

The average profile was initiated at the median age of the sample trees in the class. Data from younger trees were subsequently incorporated, sometimes resulting in an irregular pattern at the base of the average profile until all sample trees were incorporated (e.g. Figure 8.3 severe).

The different age distribution, growth curves and average profiles of the healthy trees led to the conclusion that the healthy trees selected by Baranyay were inadequate as direct controls for the mistletoe infected trees and that the volumes in Table 8.1 were not directly comparable. The moderately infected trees, however, were more suitable for direct comparison with the severe class.

Analysis of Form Changes

On trees with a bole swelling resulting from mistletoe infection, the diameter above the swelling is noticeably smaller than that below the swelling which suggested that reduced radial growth higher in the bole of infected trees might be reflected in a change in form.

In the absence of detailed stem analysis, bole volume is generally estimated from a volume equation in which volume is expressed as a function of other, more easily measured variables such as height and dbh. The British Columbia Ministry of Forests published (1976) the following equation to calculate volume of coastal western hemlock (to age 120 years):

$$\log \text{volume} = -4.418820 + 1.867780 \log \text{dbh} + 1.099890 \log \text{height}.$$

This equation is a representation of average bole form. The volume ratio, i.e., the ratio of actual volume from the stem analysis, to the volume computed from the above equation for the corresponding height and diameter, was used to indicate form change (Thomson et al. 1982).

The volume ratio, from the time tree volume reached 0.01 m^3, was examined for all trees. A ratio of 1.0 indicated that the trees were growing in the manner expected by the volume equation. With adverse mistletoe effects, a ratio of greater than 1.0 indicated slower height growth than expected for that dbh, while a ratio of less than 1.0 indicated reduced radial growth within the crown.

The change in volume ratio over the course of tree growth was studied on all sample trees. Figure 8.4 shows the volume ratio for five trees from each infection class from Redonda Island. The healthy trees have a regular change in volume ratio with time, apart from the early stages of growth. The moderately infected trees showed a gradual increase in spread of volume ratios with time, but exhibited some noticeable inflections. In the severe class,the variability in volume ratio was much more pronounced, as was the magnitude of the inflections in the volume ratio curve of individual trees. The patterns were sufficiently similar, especially with the healthy and moderate classes, that the average ratio for all trees was compared, although the inflections in the curves of individual trees will tend to cancel one another in such average curves.

The average ratio for healthy, moderately and severely infected trees from the Cowichan Lake area is shown in Figure 8.5 for volume ratio changes with time and in Fig. 8.6 for volume ratio changes with tree volume.

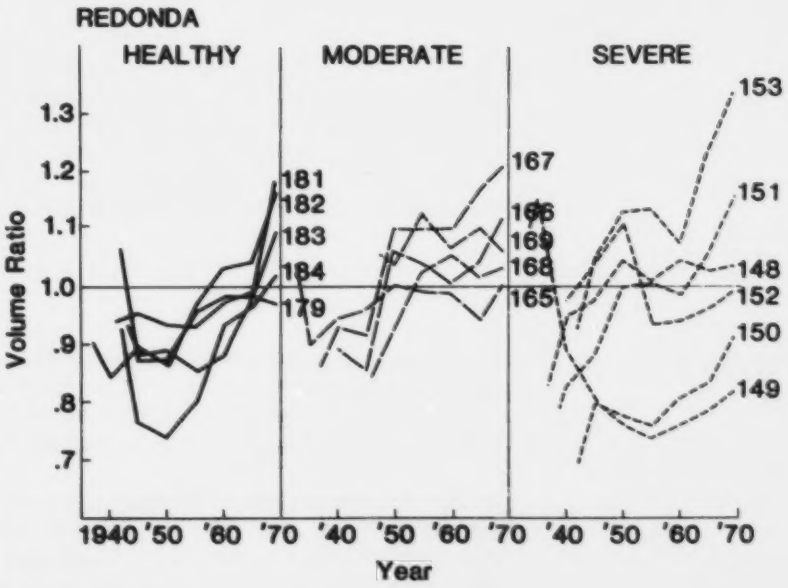


Fig. 8.4

Volume ratio of five trees from each dwarf mistletoe infection severity class from Redonda Island.

The standard deviation of volume ratio increased with infection intensity at Cowichan Lake (Figure 8.5 and 8.6) and also in the other areas studied. The decrease in volume ratio of larger trees in the severe class at Cowichan Lake was consistent with a more pronounced effect of mistletoe on the radial growth than on the height growth of the larger trees in this area.

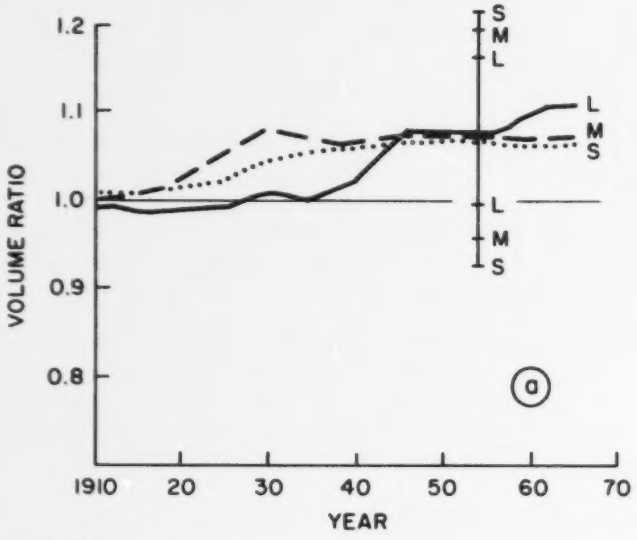


Fig. 8.5

Change in volume ratio with time in healthy (H), moderate (M) and severely (S) infected trees from Cowichan Lake. Standard deviations are shown by the vertical lines.

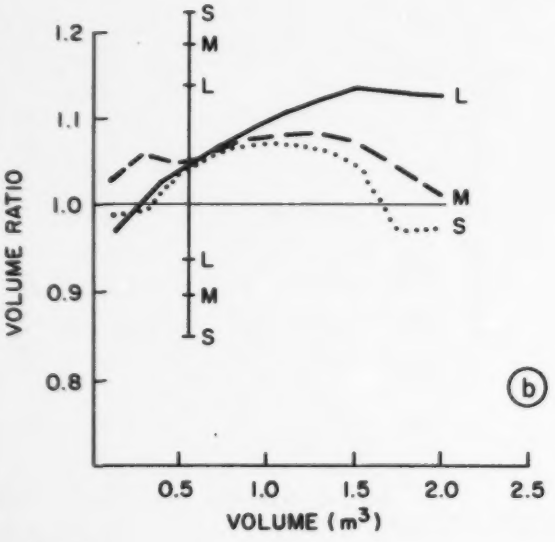


Fig. 8.6

Change in volume ratio with tree volume for same data in Fig. 7.5.

The relative impact of mistletoe on height and radial growth on individual trees apparently changed with time, resulting in inflections in the volume ratio curve. With some trees exhibiting more effect on height growth and others showing more effect on radial growth, an increase in the standard deviation resulted.

Growth Rate and Percent Live Crown

Although healthy trees could not be compared directly with infected trees, as indicated in section (a), we assumed that volume increment on similar sized trees was determined largely by the amount of foliage and that volume increment should decrease with increasing mistletoe severity rating in trees of similar size and foliage complement.

Accordingly, trees from each area were grouped into two or three size classes, depending on their volume. The volume increment in the last year of growth was then related to the percent live crown, i.e., length of crown divided by tree height times 100, which was the only measure of foliage complement available in the data set.

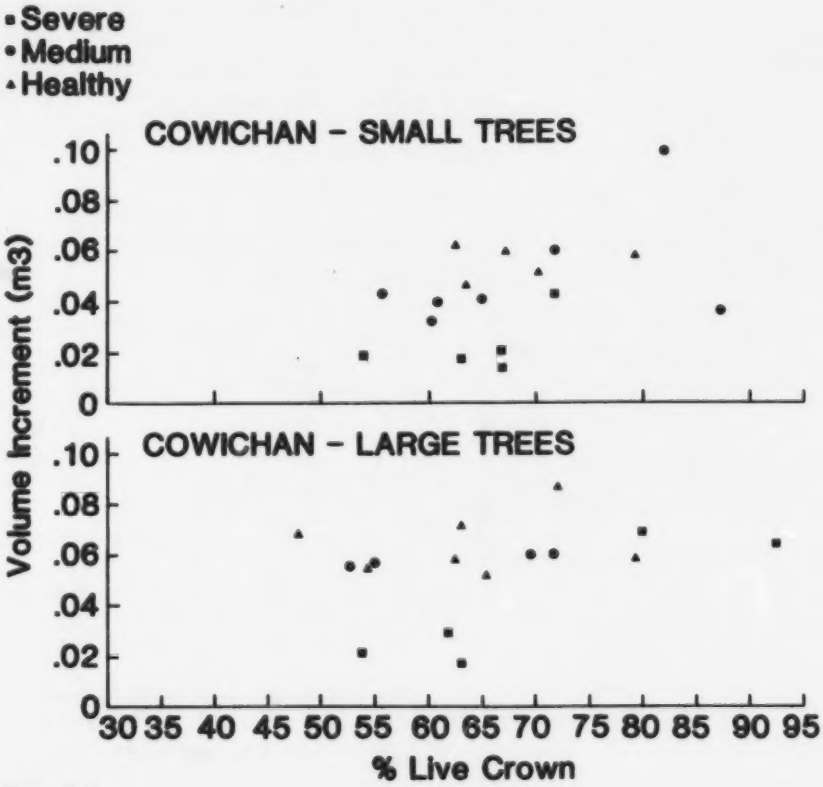


Fig. 8.7

Volume increment in relation to percent live crown of small and large trees at Cowichan Lake.

As expected a pattern of reduced growth of infected trees was evident in the Cowichan Lake trees (Figure 8.7). Severely infected trees with the smallest crowns showed the least growth. Although for trees of a particular size an increase in growth rate (volume increment) was expected for increasing live crown, this was not evident from the data.

Because of large differences in size of trees in the other areas (Table 8.1), it was not possible to define size classes with an adequate representation of all infection classes. Usually severely infected trees had to be compared with moderately infected trees, and these in turn had to be compared with healthy trees.

Severely infected trees generally had slower growth rates than the moderately infected trees. For example, at Jordan River the average increments were 0.04 m^3 and 0.02 m^3 in the moderately and severely infected trees respectively. Comparisons with the healthy trees indicated a quite different pattern from the Cowichan Lake trees. For example, in the larger trees from Jordan River instead of an expected lower increment in the mistletoe-infected trees, healthy trees and moderately infected trees, which were selected from different parts of the stand, had equivalent increments (0.05 m^3) but healthy trees produced that increment with much smaller crowns. The average percent live crown was 49% for healthy trees compared with 69% for moderately infected trees.

Volume increment appeared to be relatively insensitive to changes in percent live crown and size class at Cowichan Lake (Figure 8.7). The volume increment in the last year of growth was found to increase with increasing distance of the highest infection from the top of the tree (Figure 8.8).

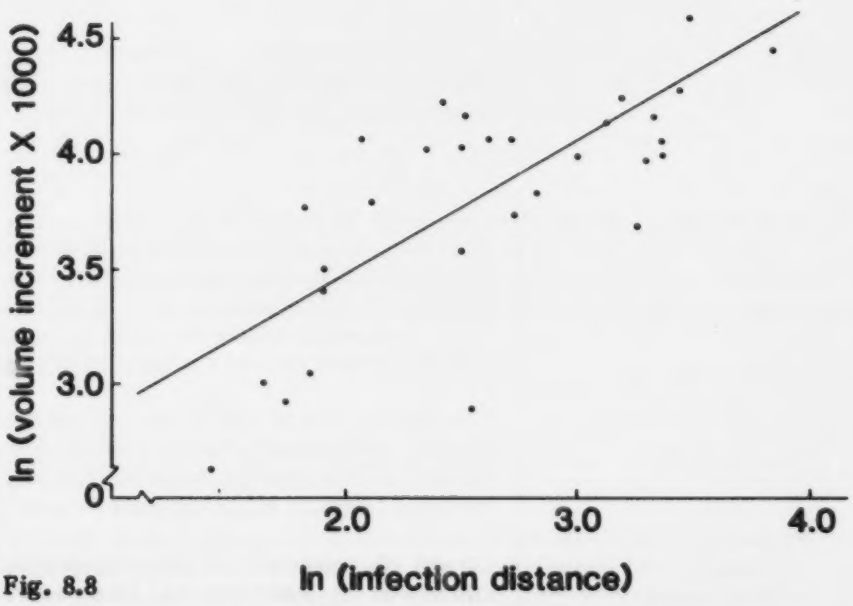


Fig. 8.8

Relationship of volume increment (m^3) in the last year of growth to the distance of the highest infection from the top of the tree.

Volume Increment-Age Relationship

The derivative of the logistic equation had a general form which provided a good fit of volume increments obtained by stem analysis, in relation to tree age (Shrimpton and Thomson 1981, 1983). Such curves were fitted to the volume increments of all average tree profiles. An example of the Jordan River average healthy tree is shown in Figure 8.9 These volume increment-age curves incorporated effects of establishment time, competition, periods of suppression, weather, and pests, and can be used to make accurate growth projections, at least over short time periods (Thomson 1983).

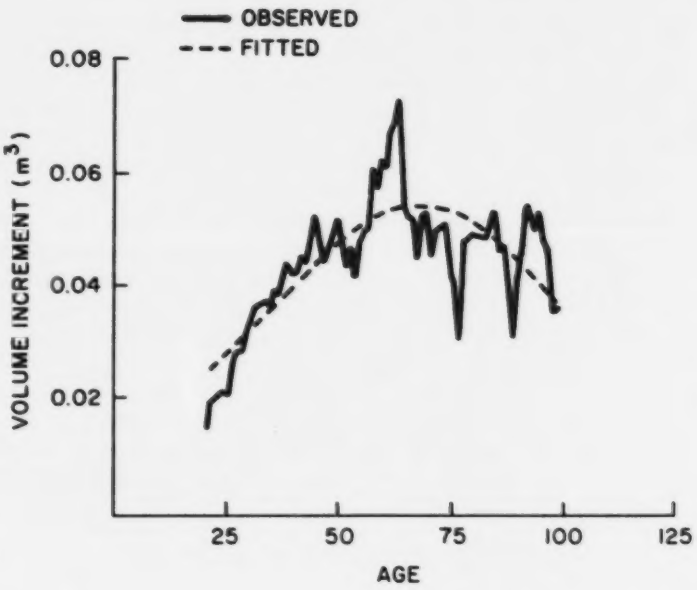


Fig. 8.9

Volume increments in relation to age of the average Jordan River healthy tree.

Curves were fitted to all average tree data as shown in Figure 8.10. The unsuitability of the healthy trees as controls was evident in all areas except Cowichan Lake. In all areas, moderately infected trees were comparable with the severely infected trees, and the severely infected trees showed reduced volume growth.

The parameters of the fitted curves were used to calculate percent volume difference between moderately and severely infected trees. Volume of the average healthy tree at Cowichan Lake was also included because all trees were from the same part of the stand.

At age 45, volume of an average severely infected tree at Redonda Island was 8% less than that of an average moderately infected tree. At age 80 at China Creek, and age 100 at Jordan River, the average severely infected tree was 17% smaller than the average moderately infected tree. For the Cowichan Lake trees at age 120, the average moderately infected tree was 22% smaller than the average healthy

tree, and the average severely infected tree was 13% smaller than the average moderately infected tree and 32% smaller than the average healthy tree.

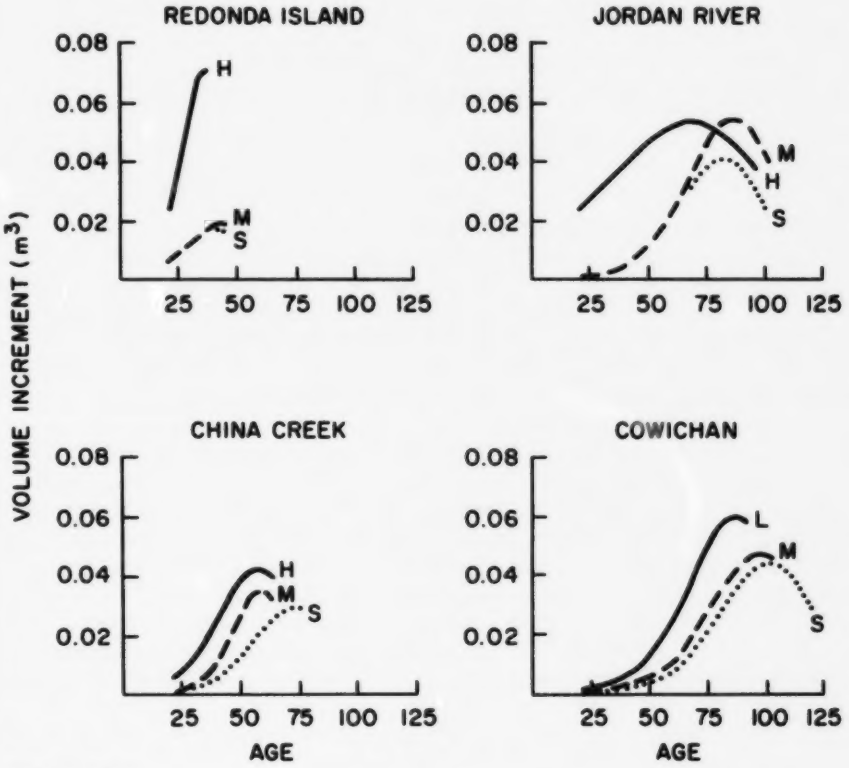


Fig. 8.10

Volume increment-age relationship of the average trees in dwarf mistletoe infection severity classes from all study areas.

Assuming a similar reduction of moderately infected trees compared with healthy trees, we estimated volume losses of approximately 15% with moderate levels of infection by hemlock dwarf mistletoe and 25% loss with severe levels. These figures are probably conservative as they did not include mortality.

Discussion

The key to accurately estimate hemlock growth losses caused by mistletoe was adequate controls for the affected tree growth measurements. When inventory-defined stands were used as the sampling base for study of mistletoe impact it was assumed that each stand was sufficiently homogeneous so that healthy trees from one part could be used as controls for dwarf mistletoe-infected trees from another part.

However, results of our stem analysis studies indicated that although a stand was homogeneous with respect to the inventory characteristics, it was not sufficiently uniform with respect to age, suppression, early growth characteristics and stand history to use healthy trees from one part as direct comparisons for infected trees from another part. Using lightly infected trees from the same area as the moderately and severely infected trees provided better comparisons although even here there were significant differences in age of trees between the infection classes. Within infection classes, trees were sufficiently similar to compare the growth patterns.

As a tree grows, infection changes as well as the effects of infection on height and radial growth, and thus on tree form. This process results in changes of volume curves. Changes in the pattern of mistletoe seed spread as crown closure occurs is one mechanism by which changes in infection distribution could occur (Thomson 1979). Changes in the relative heights of second growth and overstory trees would also change the distribution of infections (Smith 1977). Some trees respond more in diminished height growth, and others more in diminished radial growth.

Vogler and Scharpf (1981) showed a reduction in radial growth in relation to mistletoe infection of trees of comparable percent live crown. In the present study reduction of volume increment by mistletoe was demonstrated when all sample trees were from the same area. In another area where healthy and infected trees were sampled from different parts of the stand, no reduction in volume increment was evident; rather, the healthy trees had the same increment from much smaller crowns. Since percent live crown is related to stand density (Mitchell 1975), this suggested that density in the infected part of the stand was reduced, possibly through mistletoe-related mortality. Alternatively, dwarf mistletoe manifested itself to a greater degree in more open stands, eg., those with windthrow or selective logging.

Comparison of moderate and severely infested trees was facilitated by the use of fitted volume increment-age curves which permitted projection of growth to a common age. Using this approach and assuming that the ratio of healthy to moderate volume was the same as that of moderate to severe, volume losses due to hemlock dwarf mistletoe, compared to healthy trees, were conservatively estimated as reaching 15% and 25% in moderately and severely infected trees respectively. This level of impact was attained at age 80 and remained relatively constant thereafter.

Loss figures cited here are less than those reported by Smith (1969), which were based on volume increment during the last 30 years of growth. Due to the differences in age of the trees, these measurements were at different peaks of the growth curve and were thus not strictly comparable.

Acknowledgements

We thank Mr. S.M. Moncrieff for his computer programming assistance.

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Chapter 9

Video Display of Simulated Spread of Hemlock Mistletoe from the DWARF Model

*R. Alfaro**
*W. Bloomberg**

Dwarf mistletoe infection and spread were simulated by the DWARF model and were displayed on a video screen using a program developed by R. Alfaro. Principles of spread and data used in the model were outlined by W. Blomberg. Outputs and silvicultural treatments were discussed by the authors and participants.

In the first example, infection was simulated from a single, infected residual tree (Figure 9.1) which was 12 cm in diameter immediately after logging. Young trees established were indicated by small green dots on the video display. After 15 years the young trees were 3 to 17 cm diameter, the residual was 22 cm diameter and infections were present in the regeneration. At this time there were a few trees with dwarf mistletoe infection rating of 1.

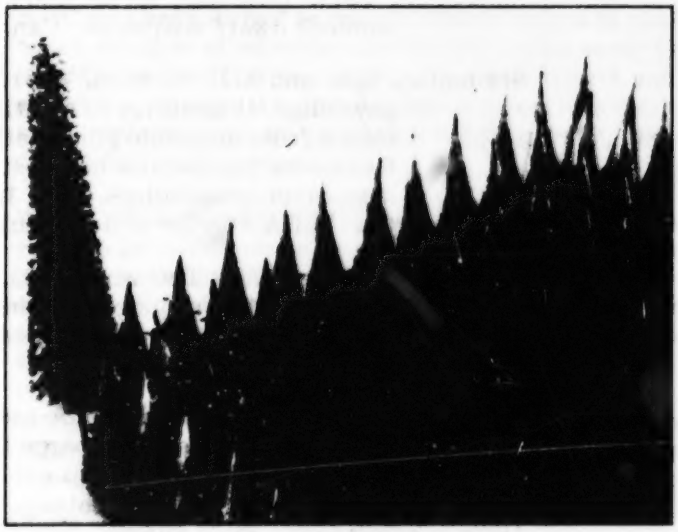

Fig. 9.1

Physical model of hemlock dwarf mistletoe on a heavily infected residual tree (left) and spread into adjacent regeneration. Each round-headed pin represents 25 infections. Based on results of computer simulation model DWARF.

Discussion of Effects of Silvicultural Treatments

Bloomberg: This graphical display shows a couple of points fairly well. First, most infections are in young trees closest to the residual. Also, infections are concentrated on larger young trees. Smaller trees closer to the residual still do not show any infection.

Smith: The small trees may be underneath the crown of the large residual tree.

Bloomberg: Yes. The model does allow for shading and dominance of small trees near the large residual tree.

Question: Could you show a directional effect of wind on dispersal of dwarf mistletoe seeds?

Bloomberg: Yes. Although not shown in this particular run, the model does allow for directional effects of wind or slope.

* R. Alfaro and W. Bloomberg are Research Scientists at the Pacific Forest Research Centre.

Question: What was the spread rate used in the model?

Bloomberg: Spread is a function of the number and size of dwarf mistletoe infections on the residual source tree. There is no specific spread rate. The actual spread is developed by simulating the dwarf mistletoe seed dispersal and the interception of seeds by trees. The actual spread in each case depends on various stand conditions, which are expressed or considered in the model. There is no average spread rate assumed.

Question: Is there a dispersal pattern then in the model?

Bloomberg: Dispersal is calculated for the individual infections. The seed dispersal function illustrated by Dick Smith (Chapter 6), is a function of the number of seeds intercepted by a tree with distance from the source. After a seed reaches a particular tree, the infection depends on a variety of factors again that are considered in the model.

The results showed that after 30 years the residual tree was 29 cm diameter and several of the younger trees were 23 cm diameter. There were many young trees around the residual tree that were rated as six, the maximum rating. There were also several rated one to three. Many of the smaller trees were now infected.

Mitchell: Would the infected smaller trees now be reinfecting other nearby trees?

Bloomberg: Yes.
Mitchell: Then for every single infected tree, the model projected dwarf mistletoe seed to other surrounding trees.

Bloomberg: Yes, this is a single tree model and it takes into account dwarf mistletoe infections on individual trees.

The next example of dwarf mistletoe spread was a tree on the edge of the plot of small trees. The first display was immediately after logging. The residual tree at this time was 12 cm in diameter.

Question: Initially were the young trees randomly distributed?

Bloomberg: Yes. The model also allows you to specify the spacing of trees, including a systematic layout.

Question: Can you also vary the species composition of a stand? For instance, a mixture of hemlock and other species?

Bloomberg: Yes, but in this run all the trees were hemlock. After 15 years, a few smaller trees showed infection. The residual tree was 22 cm diameter, the younger trees three to seven cm diameter.

Question: What distance was used for seed dispersal in the model?
Bloomberg: The distance of dwarf mistletoe seed dispersal was determined by studies of dispersal from trees and also by the distribution of seeds on individual infections at different heights.

These dispersal patterns are based on the number of seeds collected at different distances.

Question: What was the scale of the display on the video?

Bloomberg: A 14 X 14 meter plot.

Alfaro: At 30 years there was widespread infection around the residual. The healthy trees that were left were smaller in diameter.

Bloomberg: The stand density was about 3,000 stems per hectare.

Question: Can you display a density of 20,000 stems per hectare?

Bloomberg: No, we cannot go that high on the model. We have experimented only with densities of about 6,000 stems per hectare. This is a physical limitation due to the size of the computer that was available for this model. The model also allows one to determine the effects of spacing, down to very few stems per hectare, and effects of various silvicultural treatments. This particular run did not show any of these other treatments that are available.

Alfaro: At age 30, the diameters were 29 cm for the residual and 20 cm for the smaller trees which are catching up to the residual.
Mitchell: How did you grow the trees in diameter?

Bloomberg: Strictly from plot measurements. We have not used any functions for diameter growth, because we have not been able to get any that are realistic enough.

Alfaro: The last situation I would like to illustrate is where we specified a break or a buffer of ten meters between the residual and the regeneration (Figure 9.2). In this example the regeneration trees were put in specific locations.

Question: I notice the symbols used for regeneration had different proportions of red colour.

Alfaro: Yes, the proportion indicated the infection code or rating. For example, if it is half red, the rating is three. After 15 years there was no infection evident in regeneration.

Question: Were there any competition effects included?

Bloomberg: No. The model is based on juvenile stands up to age 40 and I could not determine any reliable information on competition effects. However, the model would allow competition effects to be inserted because it keeps a detailed record of the crown development and other features of the individual trees.

Cameron: Does that mean that the spatial distribution used was assumed to not have an effect on the growth rate of the individual trees?

Bloomberg: There is an approximate effect on the growth rate of individual trees. The model allows trees that are initially larger to maintain their relative growth rate. In other words, the larger, more vigorous trees will maintain their growth rate and relative position.

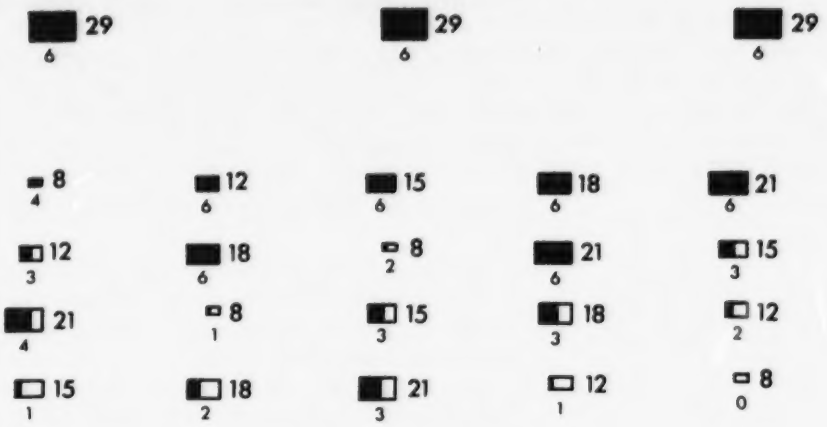

Fig. 9.2

Example of computer display showing mistletoe infection of western hemlock. Regeneration is separated by a 10m buffer from three residual trees. Output at 30 years after logging is based on computer model DWARF. Numerals indicate mistletoe infection rating, from 0 to 6 (fully shaded), and tree diameters at 1.5 m from 8 to 21 cm for regeneration and 29 cm for residuals.

Alfaro: At 30 years after logging, as shown in Figure 9.2, the infection had spread across the gap and the trees in the first row were quite heavily infected. The ones farther back, in the second and third row, had much less infection.

Bloomberg: This was to me a surprising outcome, but apparently the infections on the regeneration had built up rapidly from age 15 to 30 years, and led to subsequent spread. We have to examine the details of this in the future.

Alfaro: Could it be that the initial delay was because it takes quite a while for infections in the residual trees to produce seeds?

Bloomberg: Not so much strictly to produce seeds, but it may take ten years for the infections to build-up in residual trees to a level so that the seeds can cross the barrier space. After 15 years, with improved light conditions in residuals, we can expect the number of infections to intensify very greatly. The increase could be in the order of thousands. Therefore, even though the proportion of seed which is dispersed to ten meters is relatively low, the amount of seed being dispersed is relatively high, so that the infections could become established. However, I would like to examine the results in detail because it is surprising to me that a ten meter buffer is not sufficient to prevent the spread of dwarf mistletoe infections.

Alfaro: Could it also be that the regeneration trees of 10 to 15 centimeters diameter are much larger targets?

Bloomberg: Yes that is true and also trees of that size will have a two to three meter diameter crown that is reducing the width of the buffer. Also on the residual of 29 cm, you could expect a three to four meter crown spread or radius on the residual tree.

Question: Was this a particularly vigorous residual?

Bloomberg: Our observations and the stem analysis indicated that residuals that have been suppressed are able to respond very vigorously to release after logging or spacing. This release of the residuals will have a multiple effect on the infections. The improved light activates many previously dormant infections. In other words, increased vigour of the residuals will eventually lead to a build-up and intensification of the dwarf mistletoe infections within the crown.

Alfaro: At this age also, the display shows that there are some trees eight to ten cm diameter that have no dwarf mistletoe infection rating.

Bloomberg: I have a comment about the dwarf mistletoe rating. The rating was based on a subdivision of the crown into thirds. When infection is taking place from overstory trees, one can expect infections in the upper crown of small trees. Where an overstory seed source is absent or where the trees have outgrown the residual trees or where they are the same height, the top parts of tree crowns are free of infection and that reduces the dwarf mistletoe rating of individual trees.

It is quite feasible that in this situation the rating could actually decrease. In small trees the rating could be quite high, as a result of relatively fewer number of infections than in larger trees. Therefore the dwarf mistletoe rating is quite dependent on the size of the tree and the distribution of infections. Therefore keep in mind when you are looking at the DWARF display, that a small tree rated as a six may in fact have fewer infections than a larger tree rated as a three.

Question: The model then keeps track of the number of infections per tree?

Bloomberg: Yes, numbers and the vertical distribution of these infections.

Question: Could the model be used to determine rating systems?

Bloomberg: Yes, since the model keeps track of the distribution, size and ages of infections, it would be useful to test any new methods of rating.

Comment: Models should be able to handle densities of 10,000 stems per hectare, a common level of stocking on northern Vancouver Island and the Queen Charlotte Islands.

Bloomberg: I agree that it would be worthwhile, but we do have a limitation of machine size and capability.

Alfaro: A run of the model using the previous situation but no buffer strip, that is the young trees at a one meter by one meter spacing with residuals on the edge of the plot, showed that at age 15, there was relatively little infection of regeneration. At this time, the diameters ranged from two to seven cm. At age 30, there was uniform ratings of six for trees in the first four rows, that is four meters away from the residuals. Although it was not displayed, the actual spread in this case was much farther than in the previous case where a buffer strip had been cut.

Chapter 10

Discussion by Participants

Surveys

Wood: Were the survey results, presented at this workshop (Chapter 7), used by Canadian Forestry Service to estimate that 15% of western hemlock stands were infected by dwarf mistletoe?

Alfaro: No, the 15% was estimated by the CFS Forest Insect and Disease Survey rangers involved in coastal field work.

Wood: Recently Jeff Beale examined Ministry Inventory data for Vancouver Region from predominantly hemlock stands to determine the prevalence of dwarf mistletoe. In these inventory data only the presence of stem infections were recorded. Overall, 45 to 50% of the plots sampled had hemlock dwarf mistletoe.

Alfaro: Inventory survey records are usually conservative as dwarf mistletoe on branches is not recorded.

Bloomberg: I would like to comment that the control strategies that we discuss will be confined to juvenile stands. These offer more latitude in types of management than can be applied to older stands. However, I believe that we can still apply some kind of control in older stands.

Alfaro: Results presented here may be used to decide management strategies in various situations. For example in one stand, most of the infected trees were the larger ones and with a commercial thinning and sanitation it could be possible to obtain a good volume and also reduce the severity of dwarf mistletoe infection and the hazard for the next crop. However, commercial thinning may not give any sanitation benefits in other instances where the infection is widespread throughout the trees of various sizes and crown classes. Survey data can throw light on control strategies, even in these older stands.

Question: Was the 15% incidence figure you mentioned, confined to mature stands?

Alfaro: No, it was for the dwarf mistletoe throughout the range of hemlock, in all age classes.

Kennah: The types of stands you described do not seem very representative of the coastal area.

Bloomberg: We have seen stands being treated by Western Forest Products and Canadian Forest Products on the northern end of Vancouver Island which have conditions very similar to the ones described.

Alfaro: I suggest that commercial thinning and sanitation would be feasible only where there was a clumped distribution of dwarf mistletoe and trees were of sufficient size to be economically worthwhile. However sanitation would be very difficult where infected trees are widely spaced over an area.

Bloomberg: If dwarf mistletoe infection were concentrated in fairly large trees and smaller trees were quite free of infection in these 40 - 50 year old stands, would it be feasible to cut down these larger trees and protect the remaining trees?

Alfaro: Yes, I think it would be.

Korelus: Stands are often not pure hemlock and benefits of commercial thinning will accrue to other species that are left. Another benefit of thinning is that the final logging is much easier and results in less breakage and damage. Therefore, cost of final logging is much lower.

Alfaro: Another aspect to consider is that commercial thinning will improve light conditions and accelerate dwarf mistletoe seed production and this could result in more infection of young regeneration established after initial thinning.

Van der Kamp: I'm not impressed by the data because it is very difficult to determine dwarf mistletoe ratings and I don't think there is much difference between a 6 and a 9 point rating, because of the difficulties in seeing the crowns. However the biggest problem is that the rating should be able to tell us whether or not we are going to sustain a significant loss.

I suggest that the most critical factor in immature hemlock stands, if there is no overhead seed source, is simply the rate of height growth. The other factor is density. In many stands the upper parts of the trees are able to grow faster than the spread of the dwarf mistletoe and they remain free of infection. Dwarf mistletoe is confined to the lower part of the crown and the trees sustain no loss. In other stands, this does not happen and the dwarf mistletoe stays in the tops and upper parts of the trees. These stands sustain a major loss. These two situations seem to be the major ones that affect control of hemlock dwarf mistletoe in immature stands.

Thomson: We found from the analysis of Dick Smith's data that the distance of the uppermost infection from the top of the tree was related to the amount of impact on the tree. This ties in with your comment that we need more information.

Question: How did you rate the stand infection as light, medium or heavy?

Alfaro: It was generally based on the numerical average rating of single infected trees. Perhaps a better way to do it would be to make a weighted average on the basal area.

Smith: Did you have any opinion as to which was preferable to use, a fixed radius or a prism (variable radius) plot?

Alfaro: I don't have any opinions as to which is preferable.

Question: What survey method is used in the Vancouver Region?

Wood: We don't use any survey methods for dwarf mistletoe at present. Cruising is based on prism plots in mature and overmature stands, but these are not done to evaluate dwarf mistletoe, but to evaluate other features. Perhaps John Hall could comment on the surveys used for dwarf mistletoe as part of juvenile spacing.

Hall: The process of treating for dwarf mistletoe is basically to take down any residual trees including trees with dwarf mistletoe, and to work out site specific procedures with spacers for each individual site.

Question: How many plots per hectare would be necessary to survey dwarf mistletoe?

Alfaro: It depends on the level of accuracy required and the variation of dwarf mistletoe on each individual site.

Thomson (to Bloomberg): Do you feel that the root disease survey method would be applicable to hemlock dwarf mistletoe surveys?

Bloomberg: We tried the system with some professional foresters. We used a subplot to measure regeneration and a ten0 meter radius plot for the larger trees. We recorded infection intensity using an arbitrary ten point rating. We used this system to collect input data for the dwarf model. This method gives a good idea of the distribution of infected residuals, but was not used to determine the overall level of infection in a stand. In other words, we just used a simple line plot method.

Alexander: Is there a genetic variation in dwarf mistletoe spread rates?

Bloomberg and Smith: There is a tremendous variation in spread with site and with stand conditions.

Wood: Asked about and commented on their survey for spread of dwarf mistletoe from margins and from residual trees. He noted that in the areas that they had inspected there was very little infection from marginal trees.

In response to a question Dick Heath stated that it cost from $100 to $200 per ha for knockdown of residual trees greater than or equal to three meters in height.

Alexander: Are six point or nine point ratings really needed? Perhaps a better rating system would be simply yes or no for dwarf mistletoe infections present or absent with possibly a one or three point rating scheme.

Several of the participants suggested that the rating systems should be based on the objective of the survey. For an older stand, the product value becomes more prominent and stem infections should probably be recorded.

Fletcher and Alfaro: Perhaps we should set up a decision key to select an appropriate survey system and to decide on different silvicultural options or prescriptions.

Bloomberg: It is probably more important to rate stand dwarf mistletoe hazard, that is, major factors affecting spread, rather than rating the infection of individual trees. For instance, you should consider size and number of residual trees, site index and so on.

Smith: Rating of the middle third of the tree on the nine point system gave a good separation of growth rates, i.e., between well growing and poorly growing trees.

Several participants commented that hemlock mistletoe surveys should be combined with general silvicultural surveys such as survival surveys, and spacing surveys, that are already done.

DeBoo: There is still an obvious need for further work to determine impact of dwarf mistletoe.

Kennah: I do not favour Regional roadside surveys, but surveys for individual stands to determine the best management were the most appropriate.

Geisler: Residual falling in "backlog" dwarf mistletoe areas was about $100 per ha. Dwarf mistletoe was easy to treat and control in this manner. We are not concerned about undertaking a dwarf mistletoe impact survey.

Bloomberg and Alexander: A line plot survey of dwarf mistletoe infected residuals and regeneration for the DWARF model was undertaken in the advanced pest management course and this seemed to be a good system.

Impact

Mitchell: Is there any way of assessing the effect of an individual dwarf mistletoe infection on the contribution of carbohydrates from an individual branch?

Thomson: No, this was not studied by Baranyay.

Question: In the trees selected, is there any way of telling how long the infections had progressed?

Thomson: No, only the current level of dwarf mistletoe at the time of the survey was measured and the past levels at different periods of growth are unknown.

DeBoo: Are there studies in other Regions that can be used to indicate the overall losses to dwarf mistletoe?

Thomson: No there are no studies that I know of where the researchers have established that healthy or lightly infected trees are adequate controls to compare the growth of moderately or severely infected trees. Although there have been differences shown such as in the curves from Baranyay's data, the fact that the healthy and lightly infected trees were growing very much better than severely and moderately infected trees at early ages, indicated that there were differences within the stand, of either density or small variations in the site, that promoted the better growth of the healthy trees. Some other comparisons of growth made here indicated that there were significant effects of dwarf mistletoe on growth of trees, but the percentage effects were somewhat uncertain.

Question: Is it reasonable to assume that the larger trees would be more susceptible to infection because of the larger surface area to intercept seeds?

Thomson: Yes, that will be the subject of Bill Bloomberg's presentation. For this study we assumed that the trees of comparable size were subject to the same amount of dwarf mistletoe infection.

Bloomberg: Would you say that the best type of data to demonstrate dwarf mistletoe impact would be the growth of individual comparable trees with and without dwarf mistletoe?

Thomson: Yes, these data do not show the effect of competition nor levels of dwarf mistletoe for individual trees. However, data from Cowichan, from trees that Dick Smith established, showed a statistically significant effect of dwarf mistletoe infection on height growth at 22 years.

Van der kamp: Another problem here is that we are talking about tree growth, rather than stand growth. Is it possible that the dwarf mistletoe effect on individual trees will be compensated by the better growth of surrounding trees?

Thomson: I agree that there could be an effect on the trees but perhaps not a discernable effect on the stand. This depends on the distribution of infected trees and would have to be revealed by more detailed studies.

Several participants discussed methods for determining growth impacts including sampling of various infected trees close to one another and long-term growth and yield studies.

Thomson: Another approach could be a thinning and fertilization study, possibly in different spacing or fertilizing regimes. Dwarf mistletoe-infected trees would not respond as well as healthy or lightly infected trees.

Van der kamp: If volume losses were relatively small, say 5%, they

would be very difficult if not impossible to detect. On the other hand, if the losses were as high as 25%, they should be detectable. What level of loss do you feel would be measurable?

Thomson: It depends on the controls used in the study. In the Cowichan study, which was perhaps the best one, we detected a difference of 20% which should be a reasonable level to determine.

Alexander: If it were possible to determine the growth of Douglas-fir, as compared to hemlock on a specific site, could you use that as a measure of determining dwarf mistletoe impact?

Thomson: We attempted that in some of our budworm impact studies. There is some possibility that Douglas-fir might show patterns of release or variations in growth if the nearby hemlock is attacked, similar to some of the results of the budworm studies.

Alexander: I don't think that would be a factor to consider with dwarf mistletoe because dwarf mistletoe-infected trees draw as much if not more nutrients from the site than trees that are defoliated by the budworm.

Thomson: I agree.

Question: Have you been able to go back to the study areas and determine the source of infection, such as logging practices or whatever?

Thomson: No, we haven't. However the growth of the healthy trees compared to the other ones, suggested that they experienced a different history than the severely infected trees. For example at Jordan River, the ages of all the healthy trees were within one or two years, which suggested that they might have come in following a clearcut, whereas the severely and moderately infected trees had an age range of 50 years, which indicated they might have been surviving residuals in areas that were partially cut or logged.

Question: Were all the stands pure hemlock?

Thomson: No, they were not. Alfaro will discuss the stand composition.

Thomson: Another thing we noticed was that the recent growth of dwarf mistletoe-infected trees had slowed markedly and earlier than for healthy or lightly infected trees. The effect indicated a stagnating of the infected trees.

Question: Were the tree equations quadratic in shape?

Thomson: No, they were derivatives of logistic equations. This type of curve can be used to include variations of growth due to suppression or release as a useful way of describing the growth of different tree species in a variety of different conditions.

Question: Was the difference between ages the major reason that the trees selected for controls were not suitable?

Thomson: No, the main drawback first of all, was that the age

distribution was not the same. But the most important reason was that during the periods of early growth, where there should not be much effect of the dwarf mistletoe on growth, the healthy and lightly infected trees were growing considerably differently than the severely and moderately infected trees.

The studies at Lake Cowichan on the planted trees showed that there were no detectable effects of dwarf mistletoe on diameter, although there was a slight effect on height at age 22. In Baranyay's data the healthy and lightly infected trees grew very well through the period of time examined, whereas the moderately and severely infected trees had an initial period of growth suppression. Therefore even without dwarf mistletoe one would expect the healthy trees would be bigger than those moderately or severely infested because of their overall faster growth rates.

That is the major reason why you cannot compare the final volume of the infected and healthy trees, and attribute the difference in volume to the effects of dwarf mistletoe. However if you look at the recent volume increments, especially of moderately and severely infected trees, you can see a definite difference that is related to the amount of dwarf mistletoe present and these data indicated that dwarf mistletoe had a significant effect on the growth of these trees.

Recommendations

(The following section was based partly on notes taken by J. Muir.)

G. Kennah, Silviculture Officer, Vancouver Region, outlined a silvicultural perspective on control of hemlock dwarf mistletoe. He emphasized that there should be no special survey for dwarf mistletoe. Data required should be determined or derived from on-going surveys. He presented the following table:

Entry	Options
Pre-logging	cut-block layout, occurence of dwarf mistletoe, adjust boundaries
Post-logging	residual falling, burning, leave as is
Planning Survey (Drainage Survey in Van. Reg.)	subject to stand, prescribe treatment (juvenile spacing, stand rehabilitation, others, ?) brushing, dwarf mistletoe eradication (one plot/ha)
Spacing survey	site index species conversion density considerations

Kennah stated that we need to know where hemlock height growth is greater than the vertical rate of spread of dwarf mistletoe. Possibly

this could be determined per biogeoclimatic zone per site index measure or site index class.

Paul Wood, Pest Management Coordinator, Vancouver, stated that methods or strategies to control hemlock dwarf mistletoe should be based on opportunities. The major objective is to prevent infection of young stands. There are two basic times where this is possible: at harvest and in young stands during various entries. Action at harvest is straightforward in that the residual trees are knocked down to a height limit of three meters. For treating young stands, the key to successful treatment is the rate of western hemlock height growth. A certain number of meters per year should be set as a threshold for treatment.

If on a particular site height growth is greater than the threshold, then we should use the three meter down clause only. If the rate of height growth is less than the threshold, then we should burn or use a clause to eradicate all of the residual trees that are less than three meters in height. An additional item to deal with is perimeter sources of dwarf mistletoe infections.

For treating young stands, height growth is a key feature. This can be determined from the site index. The strategy here would be juvenile spacing, plus sanitation, which would include removal of any infected redisuals. If the height growth of the hemlock were less than or equal to the threshold, then the stand would not be spaced. (A comment here by Mike Geisler was that even if there were no spacing, in the Prince Rupert Region they would still fall any residuals greater than three meters height).

Other factors that were dicussed as considerations for treating young stands were slope, biogeoclimatic sub-zone, and alternate tree species. Alternate species should not be planted as a buffer around the perimeter of an area. Bill Bloomberg commented that we should also regularly inspect any perimeter treatment.

Bart Van der Kamp proposed that a height growth of 35 meters at 100 years would be an approximate threshold based on the observations at Haney Research Forest.

Wood stated that he believed the inspection of cut areas and enforcement of the three meter clause was a major requirement. This is a usual practice in the Vancouver Region. Kennah and Hall questioned what height growth threshold was appropriate for stands which were not to be spaced.

Dialogue

Korelus: What should be done about 60 - 70 year old stands that have questionable growth and perhaps are of poor value? Should we start harvesting the poorest second growth stands or is sanitation thinning worthwhile?

Kennah: Quite a few sales are made in young infected stands.

Alexander: If there was no impact of hemlock dwarf mistletoe or none was demonstrated, then why are guidelines for control needed?

Alfaro: Stem swellings were found on 10% of 70 year old trees that were sampled. A grading study would be necessary to determine their effect on quality. Growth reductions by dwarf mistletoes are still unknown as to their actual percentages.

Kennah: Perhaps we could look at inventory growth plots to determine effects of fertilizer and other practices on hemlock growth on different levels of dwarf mistletoe infection.

Alexander: Rayonier Company undertook a study at Jordan River several years ago, which determined lumber quality reduction associated with dwarf mistletoe infection.

Alfaro: We tried to get the data from that study, but they were not available.
(Editor's note: Correspondence provided later by N. Alexander indicated that the data were collected by J. Baranyay and were included in the reports in these proceedings.)

Smith: From our previous work, we know there was a 40% loss of wood volume associated with dwarf mistletoe infection of 110 year old hemlock trees.

Van der Kamp: Would we do anything different if we knew more about hemlock dwarf mistletoe impact? A major concern of mine is commercial thinning. Continued opening would allow dwarf mistletoe to increase.

Smith: Commercial thinning would also allow more opportunities for dwarf mistletoe sanitation.

Van der Kamp: I think the DWARF model can be used to determine various thresholds that we discussed previously for various young stands.
Bloomberg: Height growth data used in the DWARF model is not very reliable and it would be desirable to obtain better information.

Smith: The upwards rate of spread of dwarf mistletoe is variable. It depends on various factors such as the position of infections in the crown and stand density. A simple rate of height growth is probably not a realistic picture of how dwarf mistletoe spreads vertically.

Giesler: Apparently there is also geographic variation in dwarf mistletoe spread. In the Prince Rupert Region, there seems to be less spread from residual trees to adjacent trees.

Alexander: That is not surprising, considering the amount of snow that falls in the area and the large proportion of dwarf mistletoe seed that is removed mechanically by snow.

Bloomberg: For dwarf mistletoe spread, size and number of residuals per hectare are important, especially size. It is not sufficient to know that there are 20 stems per hectare of residual trees.

Smith: Twenty-five trees per hectare would give an even coverage of dwarf mistletoe seeds on a hectare and 70 trees per hectare would give severe to heavy infection of trees on the hectare. We could estimate the size, number and distribution of infections from the residuals using the DWARF model.

Wood: Perhaps we should set up a table with this type of data.

Bloomberg: Would the participants comment on the use of the model for evaluating individual stands.
Reese: The model is too slow.

Bloomberg: The interactive use of the model allows one to consider alternatives.

Wood: I would like to summarize some future routes or priorities for further research mainly by CFS on hemlock dwarf mistletoe. These include:

1. Determination of vertical spread rates of hemlock dwarf mistletoe.

2. Development of the DWARF model particularly for evaluating residuals.

3. A value study of breakage and quality associated with stem infections and other effects of dwarf mistletoe, and effects of thinning on value.

4. Determination of volume losses. This would include possibly an establishment of long term plots to determine responses to treatments, possible physiological tree response to dwarf mistletoe infection and also the development of a rating system. We probably need several rating systems for different purposes, depending on the ages of the stands and the types of treatments.

Chapter 11

Summary of Responses to the Workshop Questionnaire

*J. Muir**

The questionnaire was discussed by two groups and seven individual participants responded. The following section presents highlights of the comments and responses.

Dwarf Mistletoe Impact on Hemlock Trees or Stands

All of the participants, except one agreed that dwarf mistletoe did have an impact. The dissenting respondant felt that this question was not resolved and that further conclusions were still suspect, but this participant felt that dwarf mistletoe could have a significant impact on sites where hemlock is at a disadvantage or is competing against non-infected species.

Effects of Microsite, Tree Competition, and Dwarf Mistletoe on Tree Growth

Approximately half of the participants felt that the effects of these factors on hemlock growth had been explained adequately. Several remarked that the effects had to be better distinguished.

* J. Muir is a Forest Pathologist at the Forest Protection Branch, B.C. Ministry of Forests.

Surveys and Appraisals

All participants agreed that we should determine or estimate dwarf mistletoe impact in specific stands. Several comments were made:

Threshold values should be established that could be used in reference to specific stands.

An estimation was all that can be hoped for.

Should estimate the dwarf mistletoe population, then use researched impact relationships to estimate impacts on growth and product values.

Should distinguish between current projected impact and potential

infestation. We could get different answers depending on what we intend.

Would be helpful for documenting benefits of treatment expense. Since the benefit of treating juvenile stands is realized at a rotation age, stands with and without dwarf mistletoe at 60 to 90 years of age should be compared for volume and quality loss.

Should determine the amount of impact potential in immature stands so that better judgements could be made at juvenile spacing time for backlog spacing.

One workshop group responsed that yes we should determine the amount of impact, but research should be confined to representative stands, so that resulting data can be integrated with survey information produced from spacing surveys cruises, etc., to produce operational growth impact results.

Recommended Methods for Surveys and Appraisals in Juvenile, Older Immature, and Overmature Stands

One workshop group stated that methods for determining impact in juvenile and older immature stands should be longterm plots, using artificially infected trees, which are required to provide standardized sites and controls. The other group stated that juvenile and older immature stands should be investigated for impact potential.

Individual comments were:

Systematic systems to include an easy rating scheme, especially for tree tops.

For immature stands measure level of crop tree infection, to assess if sanitation may be undertaken.

For juvenile stands, none because dwarf mistletoe impact not significant.

For older immature to mature, perhaps compare the monetary value of stems or stands of the same volume held constant to evaluate the reductions by dwarf mistletoe.

For juveniles use a fixed radius plot, take stem counts with occular

estimation of dwarf mistletoe severity to be done at time of other surveys.

Use the six point system. For older immature use six point or nine point system, depending on purpose: nine point better for product value; for mature and overmature, recommended the nine point. In all of the above, have to determine impact relationships by research.

Potential and Actual Increases in Productivity (Tree Growth) Obtainable from Control of Dwarf Mistletoe

Generally all of the participants agreed that effects of control treatments should be estimated or determined. Several commented about how this objective was related to actually determining the amount of dwarf mistletoe impact.

Levels of Dwarf Mistletoe Infection (or Occurrence or Growth Losses) for which General Control Rules Should be Stipulated

All respondants, except one agreed that there should be maximum levels stipulated for control action. Individual comments were:

Depending on the stage of the stand, the presence of dwarf mistletoe itself would suggest consideration of control rules.

There should be a maximum but not a blanket figure.

There should be minimum levels of dwarf mistletoe infection above which control rules should be stipulated but only for certain expensive, drastic treatments, for example destruction of the stand and starting over.

Residuals after logging and where western hemlock is heavily infected,

knock down all trees blank or X meters height and manage for alternate species.

One working group commented: Determine your objective and then see if there is a survey appropriate for that need. Control rules should be stipulated only for immediately after logging. In a young stand with western hemlock a little off-site and heavily infected, manage for an alternate species.

The other working group said: yes, but depending on tree or stand age, position of pathogen in the crown, species composition of next crop, final products, etc.

Specific Levels of Dwarf Mistletoe and Appropriate Control Treatments

Comments were:

If dwarf mistletoe is present in the original stand, then presence only would be sufficient to apply the three meter rule. If dwarf mistletoe was found to be present in trees less than three meter height, for example in open dry stands, then burning should be considered (spring burning). For dwarf mistletoe control and spacing, infection levels, diameter and age of stand have to be considered. For example, consider a stand with a six point rating of two, diameter of 8.0 centimeters, age 18 years, growth rate one half centimeter per year, and a harvestable diameter of 30 centimeters. Assume a rate of increase in infection of 1 point in 15 years. Time to reach harvest is close to 44 years. dwarf mistletoe rating at harvest will equal 44 divided by 15, which equals three plus two is a total of five. Therefore trees with dwarf mistletoe ratings of two or more should be cut to avoid significant impact.

Three meter residual falling and slash burning rules are very useful, relatively cheap and should be enforced where possible, even at low levels of infestation. Reducing the knock down clause to two meters should be considered at certain times.

Residual height should be related to the residual density and stand growth rate.

General controls can be done through the three meter falling, burning, spacing trees already scheduled. For extreme measures, minimum levels of infection should be determined to justify cost of destroying advanced regeneration or young immature stands.

If you cannot really determine the levels, just do it anyway. On poorer sites, possibly stipulate lower height knock-down clauses or species conversion.

Good housekeeping as a general rule, is correct, but can you recommend even this, if impact is speculative?

A workshop group said: in most cases, current silvicultural treatments are adequate, and total eradication may be required on poorer sites, where dwarf mistletoe can overcome host's ability to outgrow it.

Standard Infection Rating Systems for Use in Hemlock Stands

Respondants were split on the question of whether to specify one or more dwarf mistletoe infection rating systems: five were in favour and three not. The working groups felt that a very simple rating should be used.

One group said that in practical terms, a rating was not needed, infection is either heavy or light. If heavy, some thought should be given, but a light infection is dealt with as a matter of course. A standard system is only good for comparisons and may be good for research.

The second group replied: Current infection rating systems are not often feasible in many western hemlock stands. Noting the presence of absence of dwarf mistletoe is adequate in some cases. There apparently is a relationship between percentage of trees infected and the infection rating per tree. A multi-phase sample should be developed to produce curves or tables for given stand types to allow field personnel to measure the number of stems infected as part of other assessment procedures and derive an average infection rating.

Recommendations on the best rating system to use were variable:

The simplest one. Rating of the top one-third of the crown would be best.

Not really necessary, except for research or if a standardized Ministry of Forests or company survey were carried out. Use only none, light or heavy. For example, use a series of pictures of residual trees which illustrate the potential impact of these individuals, that is residuals that would rate as very hazardous or non-hazardous.

We should not use infection rating systems for general use. However some kind of a system should be used to rate the minimum levels of dwarf mistletoe infection, above which control rules would be stipulated. The infection rating system specified would be a percent presence or absence on either the six or nine point scale, until we can come up with something better.

Different systems for field and for research may be appropriate.

Use a rating system as simple as possible, so implementation at the field level will not be onerous. Use fixed radius plots on sample lines with an occular estimation of the degree of infestation, possibly in classes of number of infections, much like our group of diameter classes.

Despite some problems, the six or nine point systems worked well. The nine point is better for older immature and mature, as an indication of product value, as well as growth loss.

Silvicultural Procedures and Control Strategies

Participants were asked for their recommendations for appropriate methods to use at times of forestry operations such as harvesting.

For treatment at time of harvest comments were:

Removal of the residual trees, insofar as practical.

Use the three meter rule for burn after harvest. Also locate cut block boundaries in non-infected or along non-host stands or other barriers, to prevent spread of dwarf mistletoe.

On all sites, we should use the three meter knockdown clause. If there is a high dwarf mistletoe incidence in the advance regeneration, two meters or less in height, we should then use a two meters or less height clause for knockdown or destruction of the young trees.

For site preparation, after harvest, comments were:

Continued discrimination against infected individuals.

Burn, if mechanical site preparation is not feasible.

Prescribed burning, that is burning if possible, all sites. Plant the least susceptible species appropriate for the site. Brushing and weeding, to remove infected trees.

Leave alder adjacent to the western hemlock, to block the spread. Often western hemlock is a tree being released in brushing and weeding products.

Sanitation falling.

For juvenile spacing, comments were:

Remove infected trees, rated in a specified infection level, subject to stocking requirements. In severely infected stands, consider leaving unspaced.

In sanitation spacing, prefer other species.

Select other species. If none are available, accept the least infected western hemlock.

Select and remove trees infected above the designated threshold level.

Remove residuals and infected trees wherever possible.

For commercial thinning:

Remove infected trees where in line with the primary objective of commercial thinning. Seriously consider early harvesting of extensive patches or stands of severely infected western hemlock. Always sanitation thin and remove infected residuals.

Favour removal of most heavily infected trees, subject to cost considerations.

Is it Appropriate to Develop Further a Model such as DWARF for Prediction of Volume Impacts by Mistletoe Infection Under Various Conditions?

Yes. But demonstrated impact is still suspect.

Yes.

Based on current lack of adequate controls or properly measured long-term plots, cannot make accurate comparisons. But we could give loss figures based on current data given different assumptions about the growth of the sampled stands.

No. Not until or unless volume - quality impacts can be linked to some index of observed infection.

For broad base planning, I feel we would be better off with volume impacts. We need to figure out volume impacts first in our present stands, and secondly set up long-term controlled experiments where we can monitor infected and non-infected western hemlock growth on various sites. Non-infected data can come from B.C. Forest Service, growth and yield plots where hemlock dwarf mistletoe is known to be absent.

Recommend long-term study to determine impacts as essential for pest management knowledge. Should be a priority in B.C.

I found the model of no use in forest management.

Could You Recommend or Support the Use of DWARF at Present?

Yes, at present until someone can better quantify some of the opinions bantied about during the discussion.

Use DWARF to ascertain trends in infection levels under various management regimes, thus aiding the selection of the most appropriate ones.

Use for general guidelines.

Define tree growth rate at which tree can escape the dwarf mistletoe.

Not for making silvicultural decisions, but as part of future research efforts with refinements and additional input i.e volume-quality impacts linked to index of infection. The modelling exercise is useful as a thought process to determine the level of our present understanding, but there are currently too many assumptions to make it reliable. Future use - for setting priorities on treatment - that is cutoff levels for treat - no treat, based on prediction of spread.

At present, it appears useful only on areas where backlog spacing is a consideration. Perhaps its best use would be for estimating the effect of infected cutblock perimeters. Even that isn't that useful, though, because those situations won't exist for very long after regeneration is established. I think as it was planned, it is best used for research into spread, but for grassroots management, it is not likely to be all that useful, considering management regimes in use at present. From what we've heard, current management largely controls dwarf mistletoe well enough, as timber is harvested and thinned, particularly considering that the dwarf mistletoe doesn't often kill trees, but debilitates to an unknown extent.

No - not for forest use. Need establishment of a comprehensive study package first (of which this could be a part).

I do not support this model. I recommend that researchers first find out what is needed in the practical world and then work with the people who they are trying to help. This type of post-research sales pitch should be avoided.

Further Comments

I appreciated the exposure, but my knowledge of the situation has not advanced a great deal by listening to unsubstantiated opinion. However faulty the present assumptions of dwarf mistletoe impact, there is even less evidence that it does not have a significant impact. How sad. This is what we want to know. Assumptions, that present juvenile spacing does anything to reduce the critical distribution of infected residuals, do not hold up, certainly not relative to the demonstrable creation of almost optimal stem spacing. At time of writing, I'm still trying to hold my mind open to new knowledge when it appears.

Residual cutting below the three meter height is very expensive and ineffectual, because of the slash cover. There should be more emphasis on burning, particularly on the use of spring burns, which would kill advanced regeneration and residuals without much duff destruction. Spacing in severely infected stands is probably throwing money down the drain. Much of the increased "growth" will end up in brooms, etc.

To incorporate the three meter rule as a general prescription for dwarf mistletoe control, without having explicit followup survey, to evaluate the consequences of this rule, would be unscientific and a poor management practice.

Unless volume and quality losses from dwarf mistletoes are demonstrated to be more significant than most people currently believe (from experience, gut feelings, etc.,) then our current practices seem to be adequate to control any significant dwarf mistletoe problems in future stands.

Chapter 12

Proposed Guidelines for Management of Western Hemlock Infected by Dwarf Mistletoe

*J. Muir**

* J. Muir is a Forest Pathologist at the Forest Protection Branch, B.C. Ministry of Forests.

The following procedures were formulated from general points of agreement and opinion expressed at the workshop.

Detection

Generally most coastal western hemlock stands are expected to be infected by dwarf mistletoe unless determined otherwise.

Ensure that spacers and forestry crew personnel are familiar with dwarf mistletoe brooms and swellings on boles and branches.

Surveys

Watch for and note dwarf mistletoe in usual forestry surveys. Record occurrences of dwarf mistletoe on the basis of stand area infected and by approximate percentage of stems infected. Where appropriate rate crop trees using the six or nine point infection rating system.

Control at Harvest

In areas where severely infected trees are evident, lay out cutblock boundaries to avoid or minimize infection from perimeter trees.

Apply usual three m knockdown clause at felling. If necessary, fell any residuals three m height or taller after harvest.

On an area where overstory trees were severely infected and small residuals 3 m height or less would otherwise be left:

1) On poor quality sites, destroy all small residuals, e.g., by spring slashburning.
2) On medium and good quality sites, where it is certain that juvenile spacing will be done within 15-20 years, leave small infected residuals until time of spacing when they will be cut.

Control During Juvenile Spacing

Generally cut all infected residuals from previous stand.

Subject to target stocking level, cut more severely infected hemlock.

Preferentially leave dwarf mistletoe-resistant tree species in and near areas of infected hemlock.

In stands heavily infected by dwarf mistletoe (i.e. 90% or more stems infected; average infection rating three (six point scale) or more) select one of the following options:

1) On poor sites do not space;

2) Select least-infected trees to achieve target stocking level. Top one-third of each crown must be free of infection.

3) If not possible to select resistant species and an insufficient number of suitable hemlock for crop trees, leave unspaced. For young trees, preferably clear stand and plant.

Appendix 1.

Workshop Participants

R. Alfaro, Pacific Forest Research Centre, Victoria

H. Barclay, Pacific Forest Research Centre, Victoria

V. Barge, Protection, Prince Rupert Forest Region, Smithers

J. Beale, Pathologist, Vancouver Forest Region, Burnaby

W. Beese, MacMillan Bloedel, Nanaimo

W. Bloomberg, Pacific Forest Research Centre, Victoria

I. Cameron, Research Branch, B.C. Ministry of Forests, Victoria

R. Cameron, Forest Engineer CIBAC Industries, Kitimat

A. Catto, CIPA Industries, Kitimat

R. Chisholm, B.C. Institute of Technology, Burnaby

R. DeBoo, Protection Branch, B.C. Ministry of Forests, Victoria

C. Edwards, Pacific Forest Research Centre, Victoria

V. Fletcher, Research Branch, B.C. Ministry of Forests, Victoria

M. Giesler, Silviculture, Prince Rupert Forest Region, Smithers

J. Gilmour, Silviculture Branch, B.C. Ministry of Forests, Victoria

W. Gilmour, MacMillan Bloedel, Franklin River

D. Hall, Pacific Forest Research Centre, Victoria,

J. Hall, Stand Tending Coordinator, Vancouver Forest Regional, Burnaby

R. Heath, Forester, Pacific Forest Products, Victoria

D. Hepner, Protection, Vancouver Forest Region, Burnaby

G. Kennah, Silviculture Officer, Vancouver Forest Region, Burnaby

V. Korelus, Pacific Forest Products, Victoria

R. Kosick, Tahsis, Co. Ltd.

B. McKerricher, Timber Management, Campbell River District Office

K. Mitchell, Research Branch, B.C. Ministry of Forests, Victoria

J. Muir, Protection Branch, B.C. Ministry of Forests, Victoria

R. Mullett, Silviculture Branch, BCMOF

R. Smith, Pacific Forest Research Centre, Victoria

T. Sterner, Pacific Forest Research Centre, Victoria

A. Thomson, Pacific Forest Research Centre, Victoria

D. Tuomi, B.C. Timber Ltd. Terrace

K. Tuttor, Technician, Pacific Forest Products, Victoria

J. Vallentgoed, Pacific Forest Research Centre, Victoria.

B. Van der Kamp, Faculty of Forests, University of British Columbia

P. Wood, Pest Management Coordinator, Vancouver Forest Region